PHOTOMICROGRAPHS OF IRON AND STEEL

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OF
IRON AND STEEL

BY

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WITH A FOREWORD BY

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FOREWORD

It is with great pleasure that I comply with the author's request for a brief introduction to his excellent collection of photomicrographs illustrative of the microstructure of steel in its many aspects. That there should be a need of such is an evidence of the widespread interest taken in metallography. It is of special significance to me and a source of gratification because of the part it was my good fortune to play at a time when metallography was indulgently regarded as a harmless and useless occupation. That was in the early nineties — frequently misnamed the gay nineties, if we consider the troubles we had and our difficulties in overcoming the indifference, if not the hostility, of the metallurgical world.

To the best of my knowledge the first photomicrographs of steel taken in the United States were obtained in 1892 in the laboratory of the Illinois Steel Company at South Chicago, necessarily with scanty and crude equipment. All credit to the late and much regretted W. R. Walker, at the time Manager of the South Works, who had the foresight and the courage to direct that the structure of steel be studied under the microscope, following the methods described by Sorby in his masterful — epoch making — contributions to the Iron and Steel Institute in 1886 and 1887 and the work which had then just been started in France by Osmond and Le Chatelier and in Germany by Martens. Let us sing his praise and rejoice that a steel metallurgist lived at the time possessing the necessary imagination and independence of thought to leave the ruts where others continued to flounder. Walker took great interest in this study and was satisfied with the progress made; it covered a period of about four years, when a hurricane struck the South Chicago Works — in the form of a new president — which in its violence carried away the metallographical laboratory and its occupants.

Following unsuccessful attempts to interest other steel makers in the use of the microscope, I decided to continue the work in-

dependently through the opening in Boston of some commercial laboratories in 1896 and more especially through the publication of a quarterly magazine, *The Metallographist.* The latter was an audacious thing, as I look at it now in my more matured age, for a young man to attempt single-handed. So many kind words have been spoken, however, about the part played by this publication in creating an interest in metallography and in contributing to its progress that I am glad now that I did not have at the time the wisdom and prudence to keep me from an undertaking in appearance so hazardous.

Today, it is no longer necessary to justify metallographic research. Indeed advance in metallurgy and even daily operations are now hardly conceivable without the use of the microscope.

While we may look with some complacency on the work accomplished during the last thirty years, we realize also how much there is still to be done, how many problems are awaiting their solutions, how much there is in the behavior of steel which remains unexplained or but imperfectly understood.

Younger metallurgists have a large task before them, worthy of their best efforts and promising of rich reward. It is in part to help them that the author has prepared this set of representative structures. I welcome the opportunity it affords me of placing on record the affectionate regard in which I hold the author and my appreciation of his invaluable coöperation over a period of many years.

ALBERT SAUVEUR

HARVARD UNIVERSITY,
August 16, 1928.

PREFACE

This little volume contains a set of photomicrographs of iron and steels some of which have been subjected to mechanical and thermal treatments according to standard practice. It is the author's hope that they may prove of assistance to those interested in the production, in the treatment, and in the use of these, the most important of industrial metals. The heat treatments applied have generally been those recommended by the Society of Automotive Engineers.

A list of iron and steels from which these photomicrographs were taken is given below: —

1. Pure iron
2. Commercial iron
3. Wrought iron
4. Cast steel
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5. Hot-rolled steel
6. Cold-rolled steel
   (*a*) Annealed cold-rolled steel
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   (*c*) Hardened steel
   (*d*) Hardened and tempered steel
   (*e*) Hardened and drawn steel

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    (*g*) Silicon
    (*h*) Silico-manganese
    (*i*) Chrome-tungsten
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    (*a*) Nickel
    (*b*) Chromium
    (*c*) Nickel-chromium
    (*d*) Molybdenum
    (*e*) Chrome-vanadium
12. Nitrided steel
13. Gray cast iron
14. White cast iron
15. Malleablized cast iron
16. Semi-steel
17. Chilled cast iron
18. Cast iron containing special elements

In developing the structure, the following reagents were used:

A. FOR THE MICROSTRUCTURE

1. **5% Nital** — for all carbon steels, cast irons, and some alloy steels
   95 cc. absolute methyl alcohol to which 5 cc. of concentrated nitric acid has been added.

2. **1% Nital** — Preparatory to the use of Kourbatoff's Reagent
   99 cc. absolute methyl alcohol to which 1 cc. of concentrated nitric acid has been added.

3. **Kourbatoff's Reagent** — High-speed Steels

   4 parts hydrochloric acid
   20 " iso-amyl alcohol
   75 " alcoholic solution of nitro-aniline

4. **Marble's Reagent** — Stainless Steels

   4 grams copper sulphate
   20 " water
   20 " Con. hydrochloric acid

5. **Murakami's Reagent** — Carbides and Tungstides in tungsten and high-speed steels.

   10 grams potassium ferricyanide
   10 " potassium hydroxide
   100 cc. water

6. **Sodium Picrate** — Cementite or Iron Carbide

   2 grams picric acid
   25 grams sodium hydroxide water to make 100 cc.
   Cementite blackened.

B. FOR THE MACROSTRUCTURE

LeChatelier and Lemoine Reagent — to develop dendritic segregation

10 grams	copper chloride	
40 "	magnesium chloride	(Increased contrast is de-
20 cc.	hydrochloric acid	veloped by washing off
1800 "	water	the copper deposit with
1000 "	alcohol	ammonia.)

The author is particularly indebted to Dr. Albert Sauveur, Professor of Metallurgy and Metallography in Harvard University, for his valuable suggestions and for his kindly criticism of the proof.

He wishes to express his warmest thanks to Dr. C. H. Chou for the use of Figs. 4, 5, 32, 33 and 38; to the Ludlum Steel Company for the use of information of nitrided steel, for the specimens of nitrided steel and for the specimen of Seminole steel; to

the International Nickel Company for the specimens of cast irons containing special elements, and to Barbour and Stockwell Company for the semi-steel specimen. Figs. 139, 140, 141 and 142 were reproduced from Sauveur's Metallography and Heat Treatment of Iron and Steel, by permission.

E. L. REED

CAMBRIDGE, MASSACHUSETTS,
June, 1928

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* *Normalizing:* Heating steel above its thermal critical range and cooling in air.

† *Hardening:* Heating steel above its thermal critical range followed by quenching in a suitable medium, such as oil or water.

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PURE IRON

Figs. 1-5 inclusive

PURE IRON

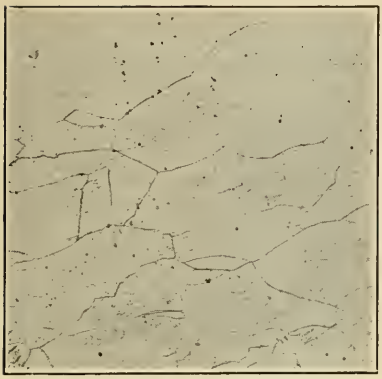

FIG. 1

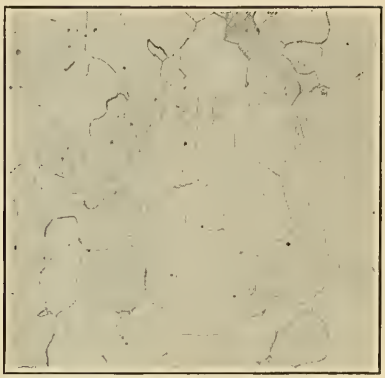

FIG. 2

FIG. 3

FIG. 1. Electrolytic iron melted in vacuum. Large grains of ferrite. Etched in 5% Nital. 50×. Original magnification, 100×.

FIG. 2. Electrolytic iron melted in vacuum and subsequently heated to 1000° C. for 15 minutes and cooled in furnace. Polyhedral grains of ferrite. Etched in 5% Nital. 50×. Original magnification, 100×.

FIG. 3. Same as in Fig. 2, more highly magnified. 250×. Original magnification, 500×.

PURE IRON

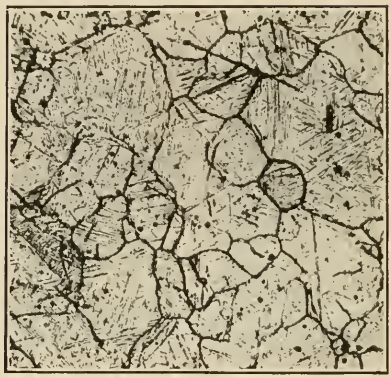

FIG. 4

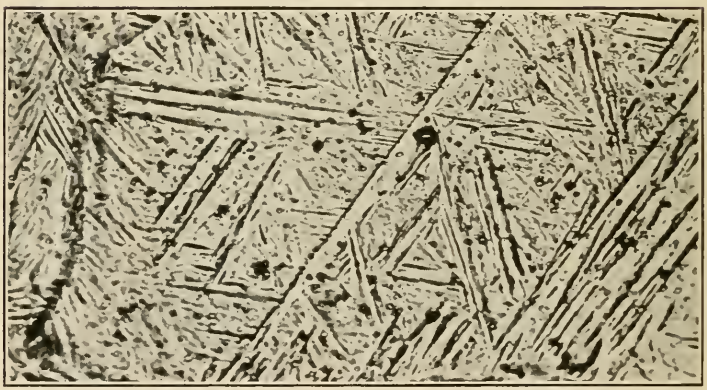

FIG. 5

FIG. 4. Electrolytic iron drastically quenched. Original austenitic grain boundaries and martensitic structure. 50×. Original magnification, 100×.

FIG. 5. Same as in Fig. 4, more highly magnified. 250×. Original magnification, 500×.

COMMERCIAL IRON

Figs. 6-19 inclusive

COMMERCIAL IRON

FIG. 6

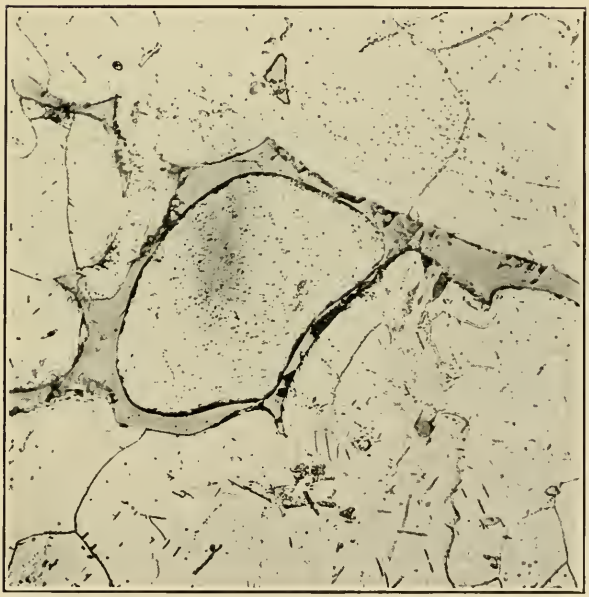

FIG. 7

FIG. 6. Iron oxide in commercially pure iron. Etched in 5% Nital. 250×. Original magnification, 500×.

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COMMERCIAL IRON

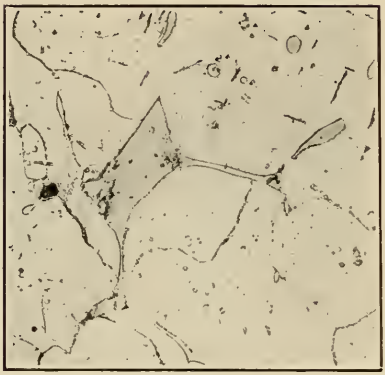

FIG. 8

FIG. 9

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FIG. 9. Sulphur print of high sulphur-iron ingot. Sulphur content, 0.62%. Actual size.

COMMERCIAL IRON

FIG. 10

FIG. 11

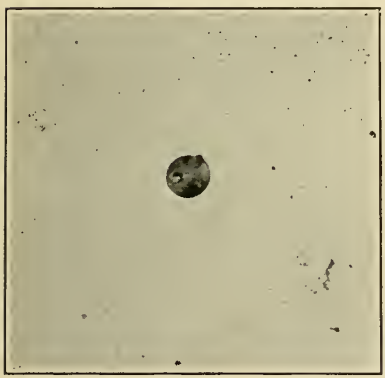


FIG. 12

FIG. 13

FIG. 10. Iron nitride needles in ferrite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 11. Iron nitride needles in ferrite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 12. Iron silicate in iron. Unetched. 250×. Original magnification, 500×.

FIG. 13. Sand grain in iron. Unetched. 250×. Original magnification, 500×.

COMMERCIAL IRON

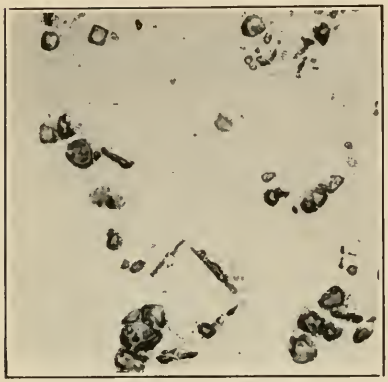


FIG. 14

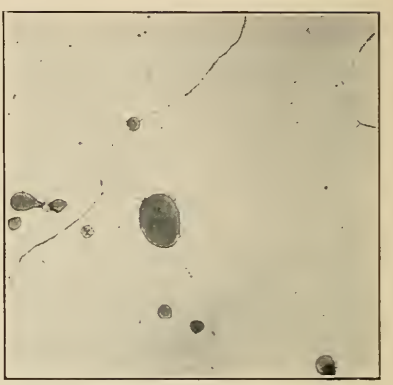


FIG. 15

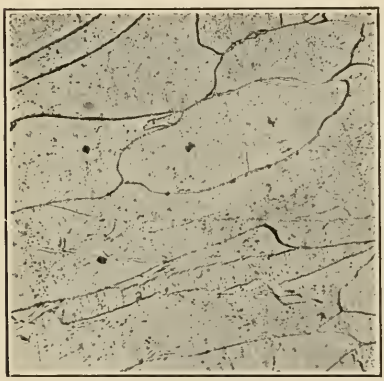


FIG. 16

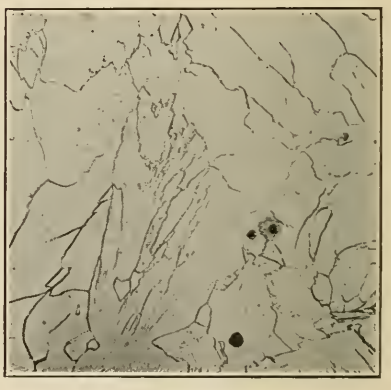


FIG. 17

FIG. 14. Grains of alumina (Al_2O_3), in ferrite. Unetched. 250×. Original magnification, 500×.

FIG. 15. Manganese sulphide in ferrite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 16. Armco iron. Cold worked. Deformed ferrite grains. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 17. Armco iron heated nearly to melting point and quenched in cold water. Etched in 5% Nital. 250×. Original magnification, 500×.

COMMERCIAL IRON

FIG. 18

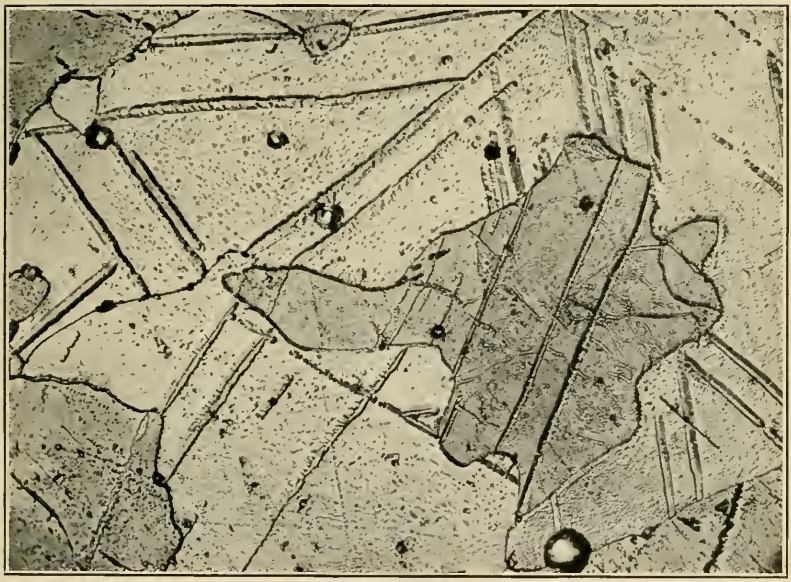


FIG. 19

FIG. 18. Neumann bands in ferrite. Etched in 5% Nital. 75×. Original magnification, 100×.

FIG. 19. Neumann bands in ferrite. Etched in 5% Nital. 375×. Original magnification, 500×.

WROUGHT IRON

Figs. 20-24 inclusive

WROUGHT IRON

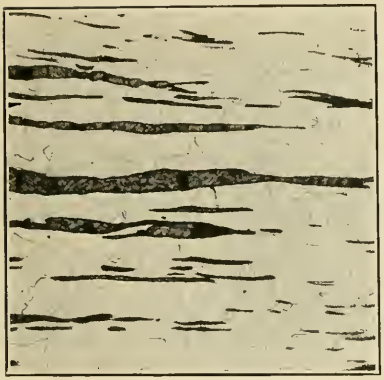


FIG. 20

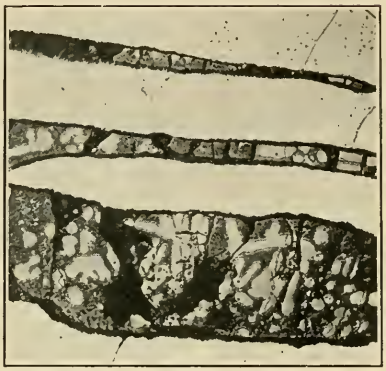


FIG. 21

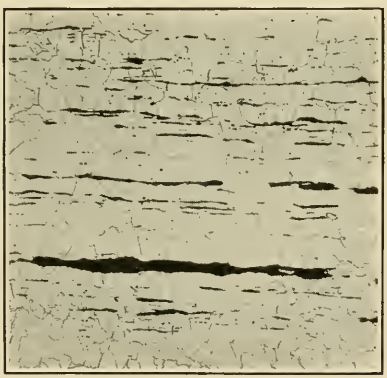


FIG. 22

FIG. 20. Muck bar. Longitudinal section. Etched in 5% Nital. 50×. Original magnification, 100×.

FIG. 21. Muck bar. Longitudinal section, showing duplex structure of slag. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 22. Wrought iron. Longitudinal section. Etched in 5% Nital. 50×. Original magnification, 100×.

WROUGHT IRON

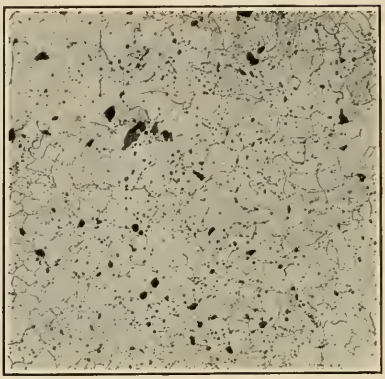


FIG. 23

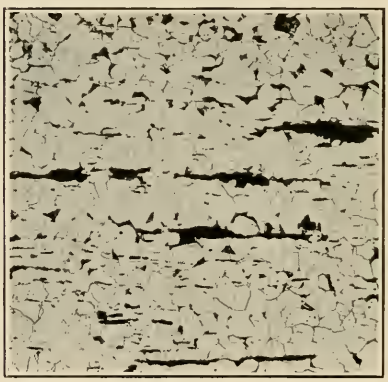


FIG. 24

FIG. 23. Wrought iron. Transverse section. Etched in 5% Nital. 50×. Original magnification, 100×.

FIG. 24. Wrought iron. Longitudinal section. Black fibers of slag running in the direction of rolling. Small black pearlite grains situated at the boundaries of the white ferrite grains. Etched in 5% Nital. 50×. Original magnification, 100×.

IMPURITIES IN STEEL

Figs. 25-29 inclusive

IMPURITIES IN STEEL

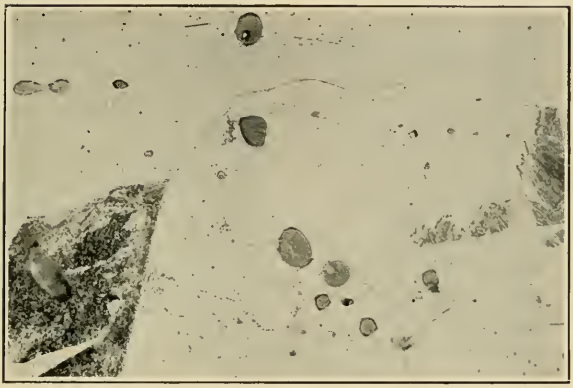


FIG. 25

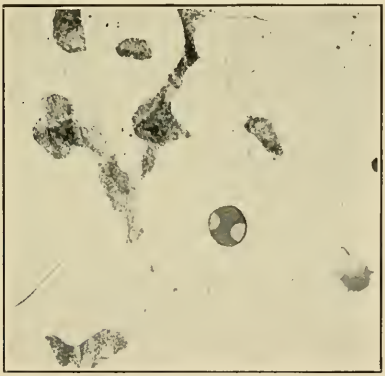


FIG. 26

FIG. 25. Manganese sulphide in low carbon cast steel. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 26. An inclusion in low carbon cast steel. Etched in 5% Nital. 250×. Original magnification, 500×.

IMPURITIES IN STEEL

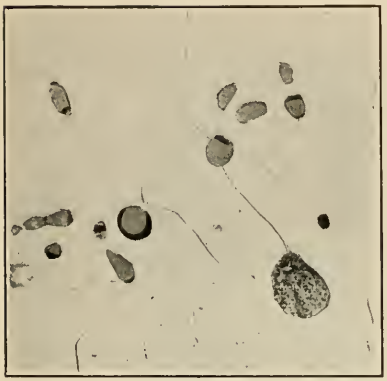


FIG. 27

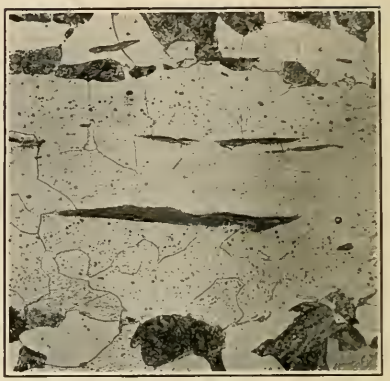


FIG. 28

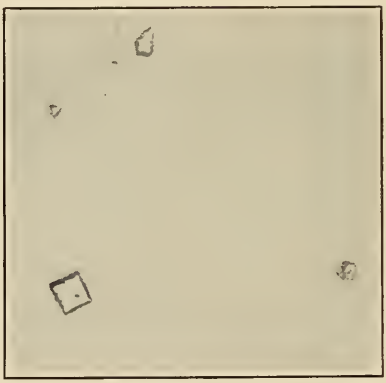


FIG. 29

FIG. 27. Inclusions in low carbon cast steel. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 28. Elongated particles of manganese sulphide in screw stock material. Carbon, 0.20%; manganese, 0.70%; sulphur, 0.11%. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 29. Cubic crystal of titanium nitride or cyanitride in titanium treated tool steel. The cubic crystal is pink in color. 250×. Original magnification, 500×. Unetched.

CAST STEEL

AND

ANNEALED CAST STEEL

Figs. 30-51 inclusive

CAST STEEL

FIG. 30

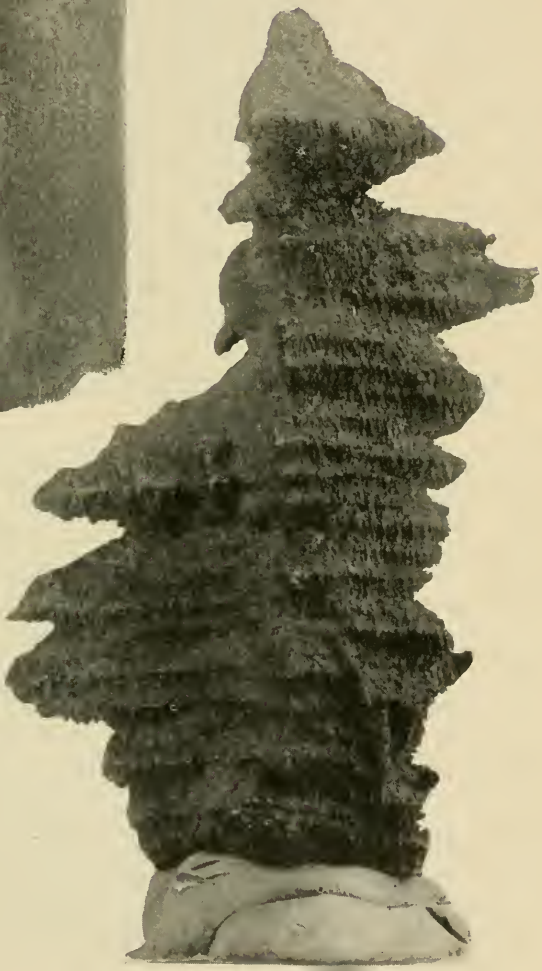


FIG. 31

FIG. 30. Photograph of a cast steel ingot cut longitudinally showing the pipe in the upper part of the ingot. One-half natural size.

FIG. 31. Photograph of a crystallite, sometimes called a dendrite, a fir tree crystal, or a pine tree crystal. These dendrites are found in pipes in castings. Actual size.

CAST STEEL

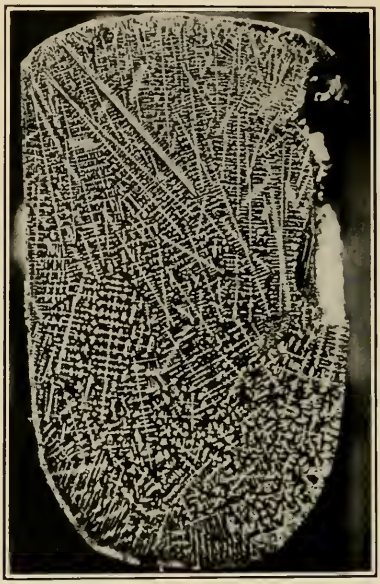


FIG. 32

FIG. 33

FIG. 32. Macrostructure of a steel ingot containing 0.52% carbon and 0.097% phosphorus. Dendritic segregation. Etched in LeChatelier's reagent. 1.7×. Original magnification, 2.5×.

FIG. 33. Microstructure of ingot shown in Fig. 32. Etched in 5% Nital. Original magnification, 66.7×.

CAST STEEL

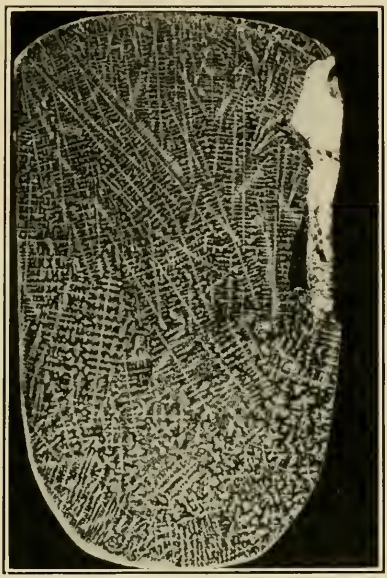


FIG. 34

FIG. 35

FIG. 34. Macrostructure of ingot shown in Fig. 32, after annealing one hour at 1000° C. Persistence of dendritic segregation. Etched in LeChatelier's reagent. 1.7×. Original magnification, 2.5×.

FIG. 35. Microstructure of ingot shown in Fig. 34. Etched in 5% Nital. 66.7×. Original magnification, 100×.

CAST STEEL

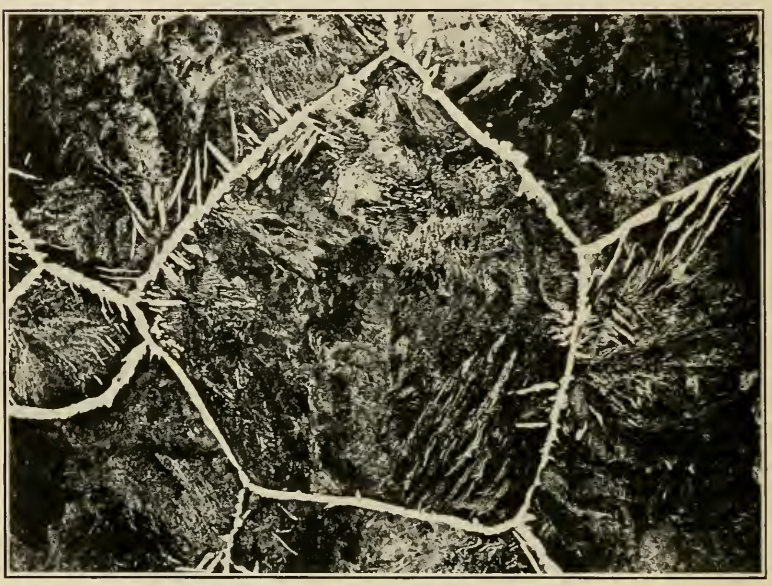


FIG. 36

FIG. 36. Steel. Cast. 0.50% carbon. Large sorbito-pearlite grains surrounded by a ferrite membrane from which occasionally radiates ferrite. Etched in 5% Nital. 50×. Original magnification, 100×.

CAST STEEL

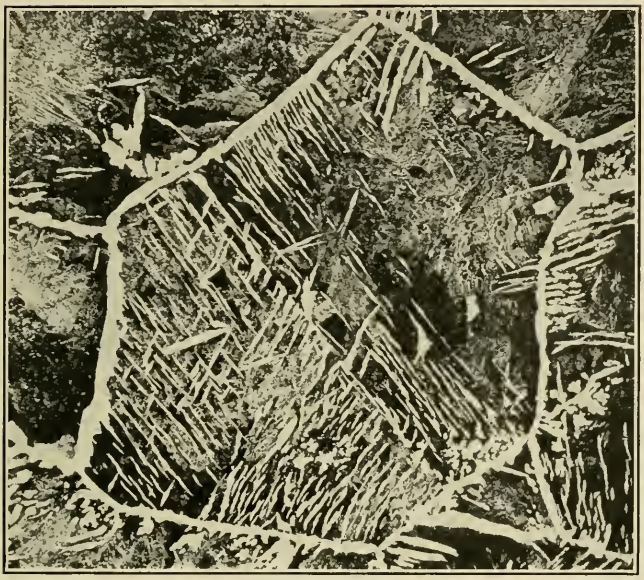


FIG. 37

FIG. 37. Steel. Cast. 0.50% carbon. Large sorbite or sorbito-pearlite grains surrounded by a ferrite boundary from which ferrite radiates, also some ferrite is precipitated along the octahedral crystallographic planes. Etched in 5% Nital. 50×. Original magnification, 100×.

CAST STEEL

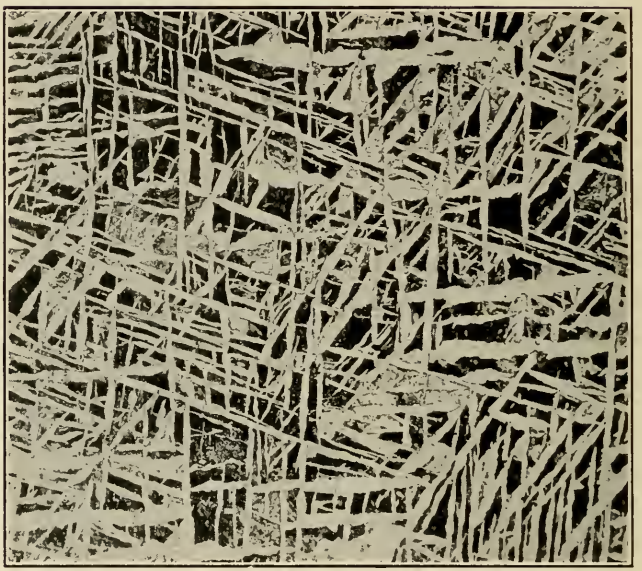


FIG. 38

FIG. 38. Steel. Cast. 0.50% carbon. Slowly cooled through the critical range. The ferrite is retained in the crystallographic planes. The structure is known as Widmanstätten or cleavage structure. Etched in 5% Nital. 50×. Original magnification, 100×.

CAST STEEL

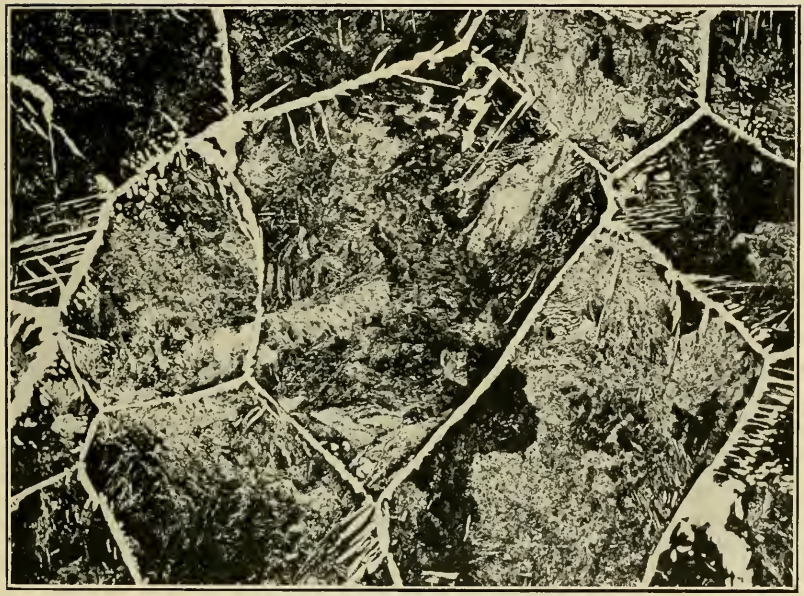


FIG. 39

FIG. 39. Steel. Cast. 0.50% carbon. Network structure. Etched in 5% Nital. 50×. Original magnification, 100×.

CAST STEEL

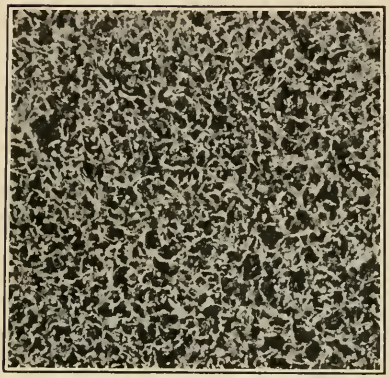


FIG. 40

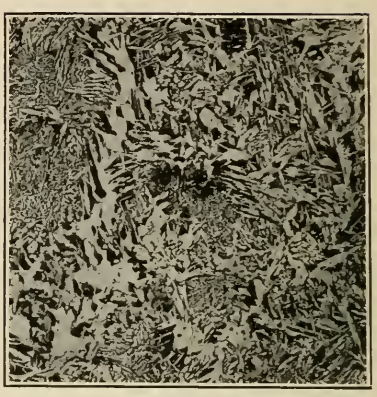


FIG. 41

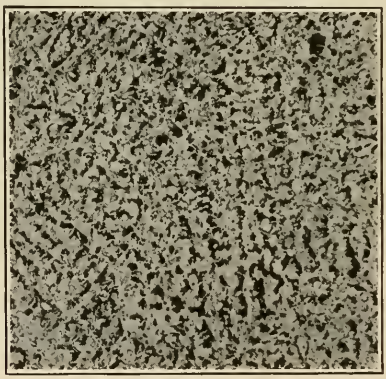


FIG. 42

FIG. 40. Same steel as shown in Fig. 39 after annealing 5 hours at 850° C. Grain refinement. Etched in 5% Nital. 50×. Original magnification, 100×.

FIG. 41. Steel. Cast. 0.40% carbon. Etched in 5% Nital. 50×. Original magnification, 100×.

FIG. 42. Same steel as shown in Fig. 41, after annealing 5 hours at 850° C. Etched in 5% Nital. 50×. Original magnification, 100×.

CAST STEEL

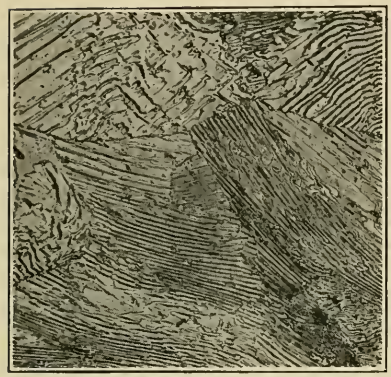


FIG. 43

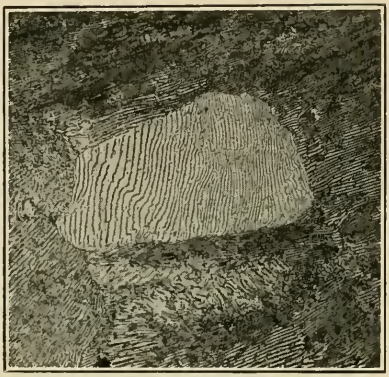


FIG. 44

FIG. 45

FIG. 43. Steel. Cast. 0.85% carbon. Lamellar pearlite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 44. Another spot on same specimen, the structure of which is shown in Fig. 43. 250×. Original magnification, 500×.

FIG. 45. Steel. Cast. 1.10% carbon. Large grains of pearlite surrounded by a fine membrane of cementite. Etched in 5% Nital. 50×. Original magnification, 100×.

CAST STEEL

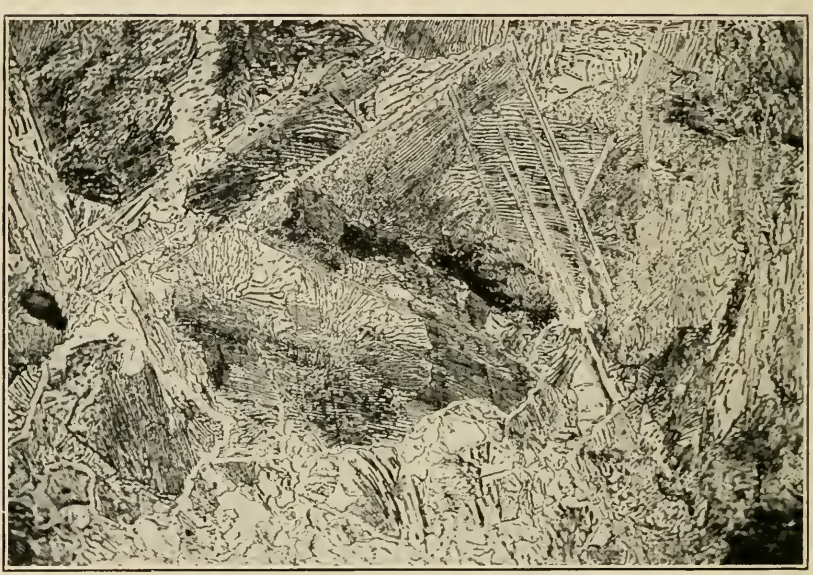


FIG. 46

FIG. 46. Steel. Cast. 1.25% carbon. Cementite partially rejected along cleavage planes and around grain boundaries. Etched in 5% Nital. 375×. Original magnification, 500×.

CAST STEEL

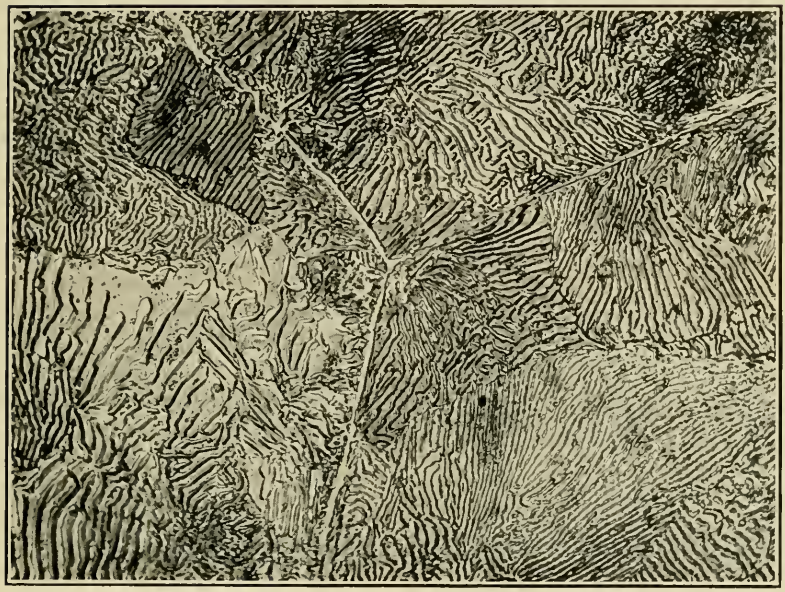


FIG. 47

FIG. 47. Steel. Cast. 1.25% carbon. Cementite persisting around boundaries of pearlite grains. Etched in 5% Nital. 375×. Original magnification, 500×.

CAST STEEL

FIG. 48

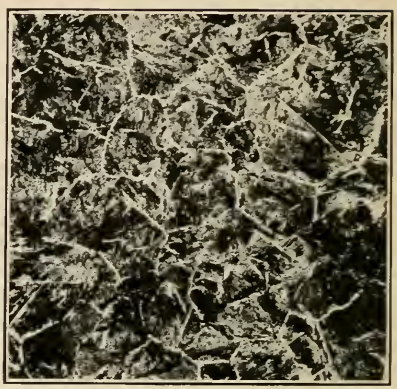


FIG. 49

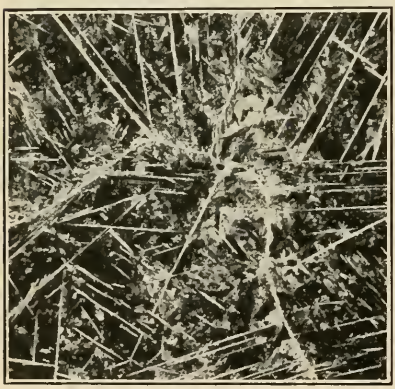


FIG. 50

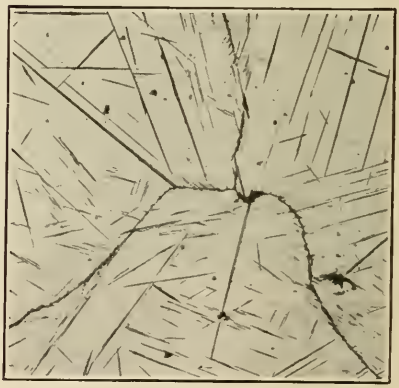


FIG. 51

FIG. 48. Steel. Cast. 1.40% carbon. Cementite between cleavage planes. Etched in 5% Nital. 50×. Original magnification, 100×.

FIG. 49. Same steel shown in Fig. 48 after annealing 5 hours at 850° C. Cementite rejected to boundaries of pearlite grains. Etched in 5% Nital. 50×. Original magnification, 100×.

FIG. 50. Steel. Cast. 1.40% carbon. Cementite rejected to the boundaries and separated along cleavage planes. Etched in 5% Nital. 50×. Original magnification, 100×.

FIG. 51. Same spot as shown in Fig. 50 after repolishing and etching in boiling sodium picrate. The cementite is blackened.

HOT-ROLLED STEEL

Figs. 52-61 inclusive

HOT-ROLLED STEEL

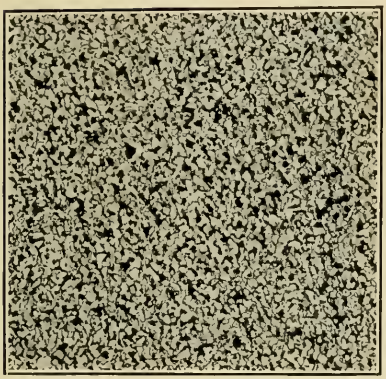


FIG. 52

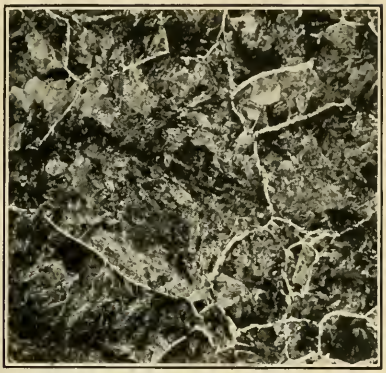


FIG. 53

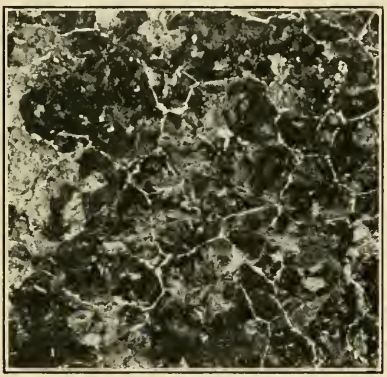


FIG. 54

FIG. 52. Steel. Hot-rolled. 0.30% carbon. Correct finishing temperature, namely, just above critical range. Etched in 5% Nital. 100×.

FIG. 53. Steel. Hot-rolled. 0.50% carbon. Finishing temperature considerably above the critical range. Etched in 5% Nital. 50×. Original magnification, 100×.

FIG. 54. Steel. Hot-rolled. 0.50% carbon. Finishing temperature considerably above the critical range. Etched in 5% Nital. 50×. Original magnification, 100×.

HOT-ROLLED STEEL

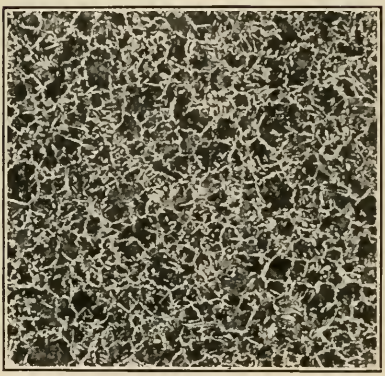


FIG. 55

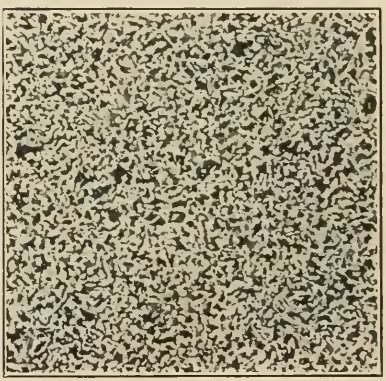


FIG. 56

FIG. 55. Steel. Hot-rolled. 0.50% carbon. Finishing temperature just above the critical range. Etched in 5% Nital. 50×. Original magnification, 100×.

FIG. 56. Steel. Hot-rolled. 0.50% carbon. Finishing temperature near the critical range. Etched in 5% Nital. 50×. Original magnification, 100×.

HOT-ROLLED STEEL

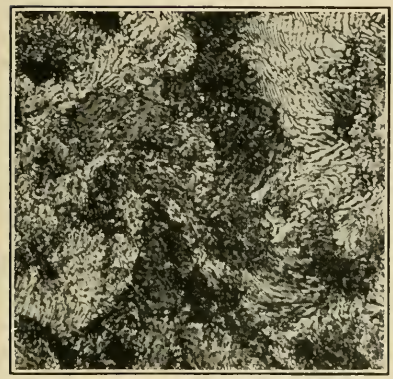


FIG. 57

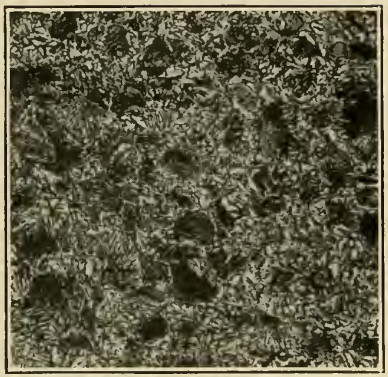


FIG. 58

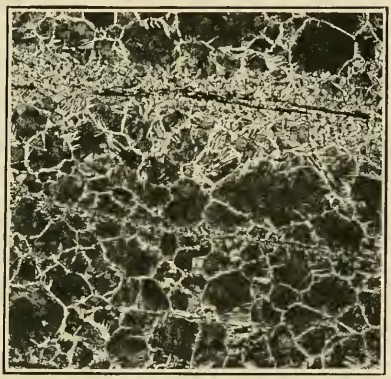


FIG. 59

FIG. 57. Steel. Hot-rolled. 0.85% carbon. Sorbito-pearlite. Etched in 5% Nital. 500×.

FIG. 58. Steel. Hot-rolled. 1.25% carbon. Sorbito-pearlite and traces of cementite boundaries around grains. Finishing temperature near the critical range. Etched in 5% Nital. 500×.

FIG. 59. Steel. Hot-rolled. 0.50% carbon. Banded structure. The light-colored bands are rich in phosphorus and also contain many inclusions. Etched in 5% Nital. 50×. Original magnification, 100×.

HOT-ROLLED STEEL

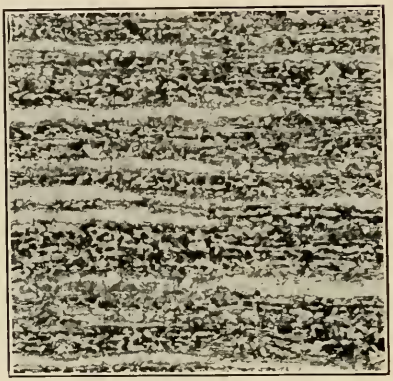


FIG. 60

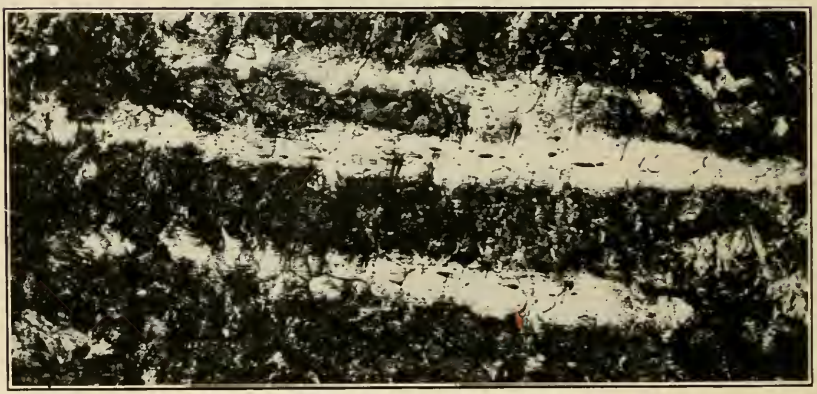


FIG. 61

FIG. 60. Steel. Hot-rolled. 0.50% carbon. Banded structure. The white bands are rich in phosphorus and are not etched by the reagent. Etched in LeChatelier's reagent. 50×. Original magnification, 100×.

FIG. 61. Steel. Hot-rolled. 0.85% carbon. Banded structure caused by persistent dendritic segregation. The white bands contain impurities. Etched in LeChatelier's reagent. 50×. Original magnification, 100×.

COLD-ROLLED STEEL

AND

ANNEALED COLD-ROLLED STEEL

Figs. 62-64 inclusive

COLD-ROLLED STEEL AND ANNEALED COLD-ROLLED STEEL

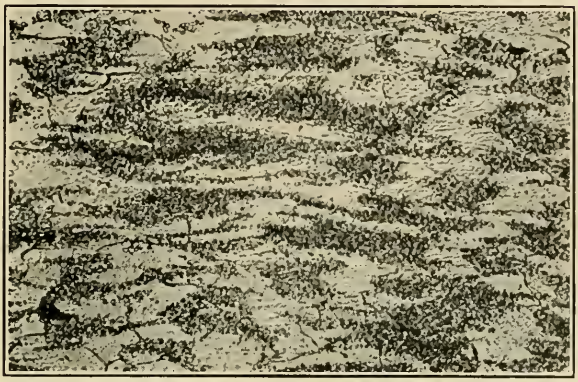


FIG. 62

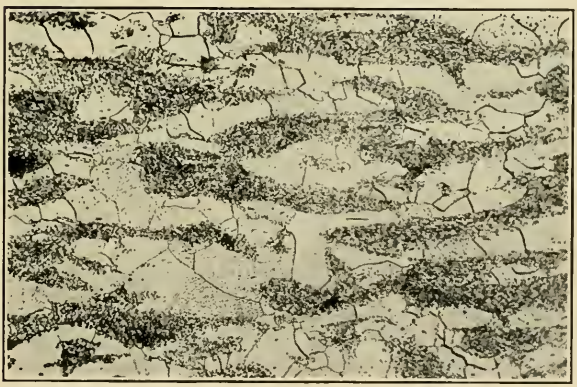


FIG. 63

FIG. 62. Steel. Cold-rolled. 0.30% carbon. Deformed ferrite and pearlite grains. Etched in 5% Nital. 375×. Original magnification, 500×.

FIG. 63. Steel. Cold-rolled. 0.30% carbon. Annealed at 550° C. Equiaxed ferrite grains and deformed pearlite. Etched in 5% Nital. 375×. Original magnification, 500×.

COLD-ROLLED STEEL AND ANNEALED COLD-ROLLED STEEL

FIG. 64

FIG. 64. Steel. Cold-rolled. 0.30% carbon. Annealed at 850° C. Equiaxed ferrite and pearlite grains. Etched in 5% Nital. 375×. Original magnification, 500×.

ANNEALED HOT-ROLLED STEEL

Figs. 65-79 inclusive

ANNEALED HOT-ROLLED STEEL

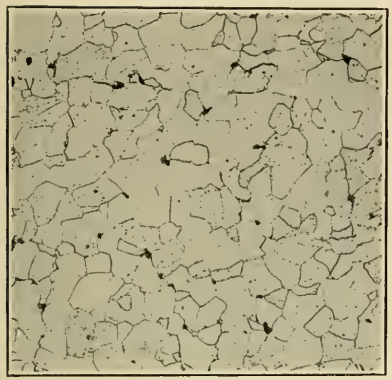


FIG. 65

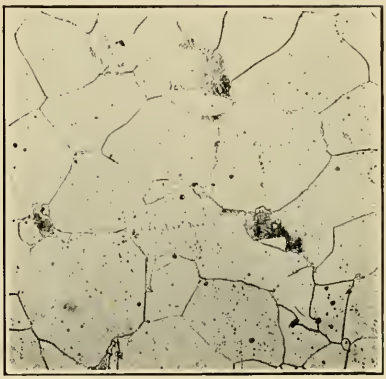


FIG. 66

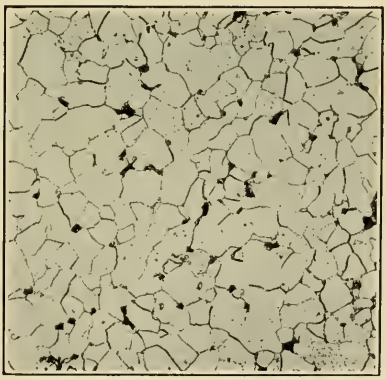


FIG. 67

FIG. 65. Steel. Annealed. 0.08% carbon. Polyhedral grains of ferrite and small black islands of pearlite. Etched in 5% Nital. 100×.

FIG. 66. Steel. Annealed. 0.08% carbon. Pearlite grains resolved under high magnification. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 67. Steel. Annealed. 0.10% carbon. Polyhedral grains of ferrite and dark grains of pearlite. Etched in 5% Nital. 100×.

ANNEALED HOT-ROLLED STEEL

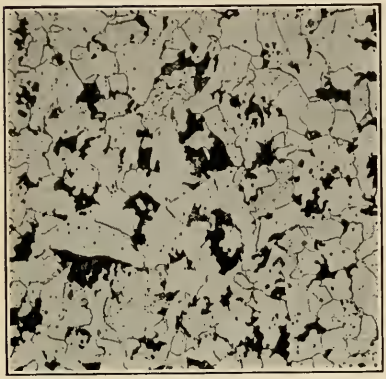


FIG. 68

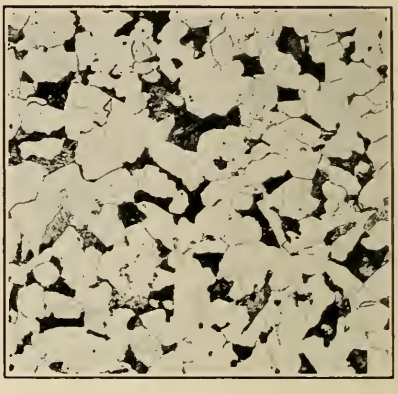


FIG. 69

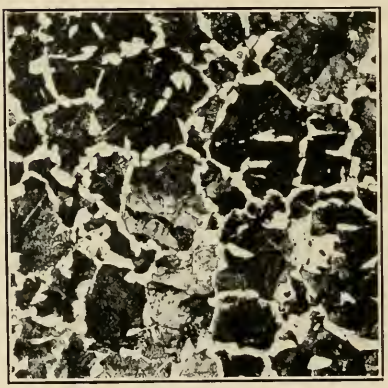


FIG. 70

FIG. 68. Steel. Annealed. 0.20% carbon. Ferrite and pearlite grains. Etched in 5% Nital. 100×.

FIG. 69. Steel. Annealed. 0.30% carbon. Ferrite and pearlite grains. Etched in 5% Nital. 100×.

FIG. 70. Steel. Annealed. 0.50% carbon. Pearlite grains surrounded by a membrane of ferrite. Etched in 5% Nital. 100×.

ANNEALED HOT-ROLLED STEEL

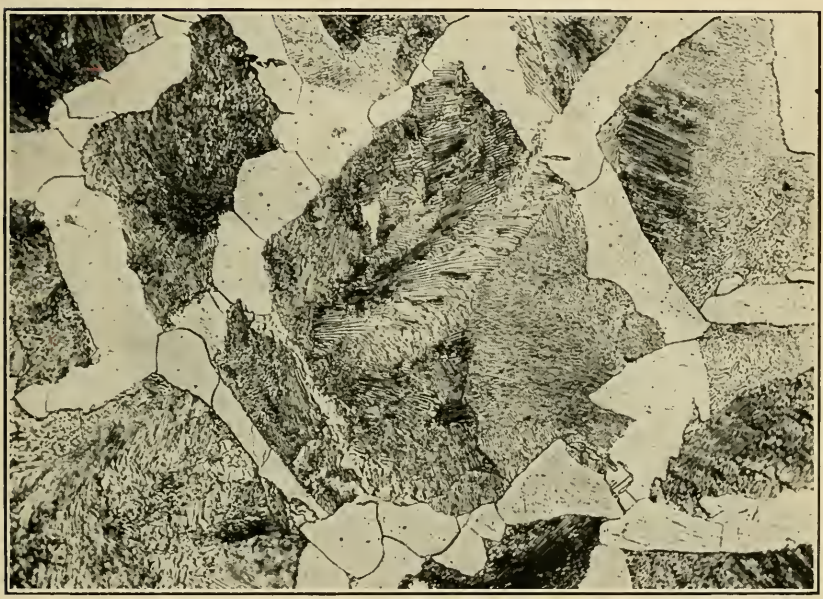


FIG. 71

FIG. 71. Steel. Annealed. 0.50% carbon. Ferrite surrounding grains of sorbito-pearlite. Etched in 5% Nital. 375×. Original magnification, 500×.

ANNEALED HOT-ROLLED STEEL

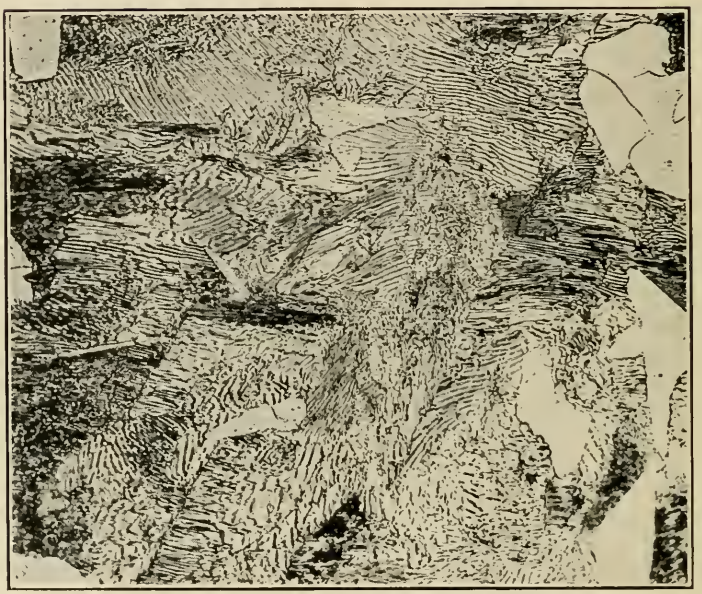


FIG. 72

FIG. 72. Same steel as shown in Fig. 71. Ferrite and pearlite. Etched in 5% Nital. 375×. Original magnification, 500×.

ANNEALED HOT-ROLLED STEEL

FIG. 73

FIG. 73. Steel. Annealed. 0.85% carbon. 100% pearlite. Etched in 5% Nital. 75×. Original magnification, 100×.

ANNEALED HOT-ROLLED STEEL

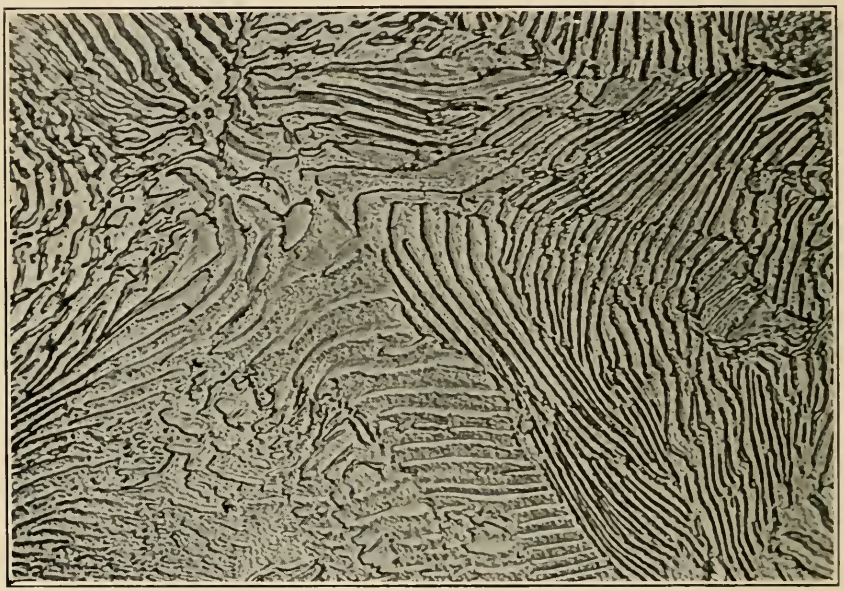


FIG. 74

FIG. 74. Steel. Annealed. 0.85% carbon. Lamellar pearlite. Etched in 5% Nital. 750×. Original magnification, 1000×.

ANNEALED HOT-ROLLED STEEL

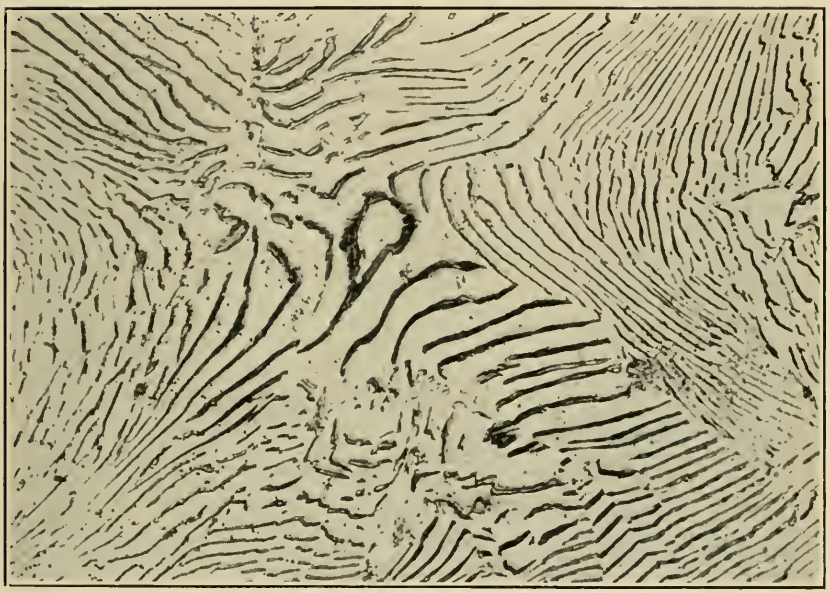


Fig. 75

Fig. 75. Same spot as shown in Fig. 74, after repolishing and etching in boiling sodium picrate. The cementite in the pearlite is blackened. 750×. Original magnification, 1000×.

ANNEALED HOT-ROLLED STEEL

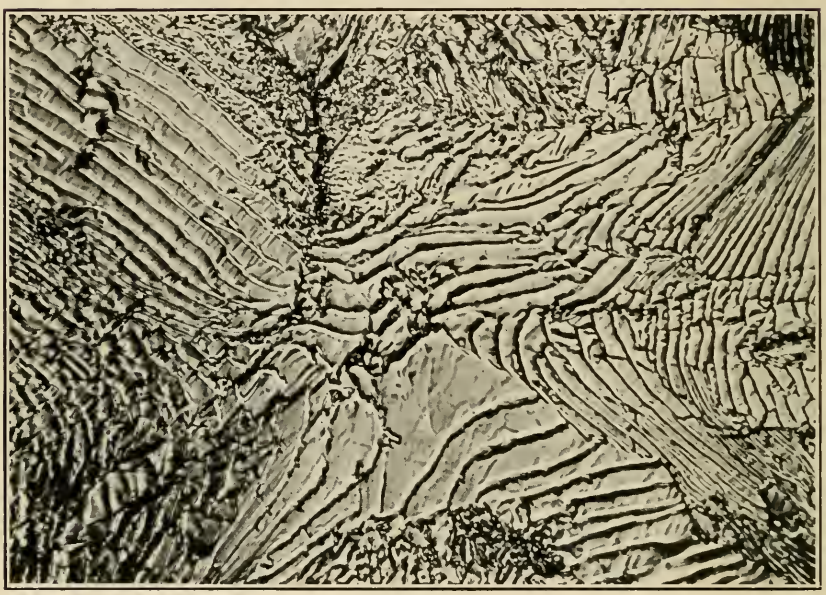


Fig. 76

Fig. 76. Same spot as shown in Fig. 75 after repolishing and etching in LeChatelier's reagent. 750×. Original magnification, 1000×.

ANNEALED HOT-ROLLED STEEL

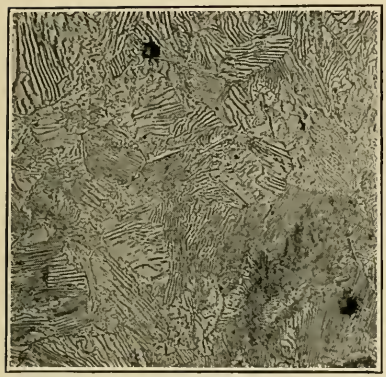


FIG. 77

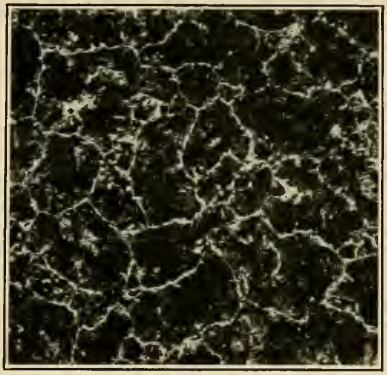


FIG. 78

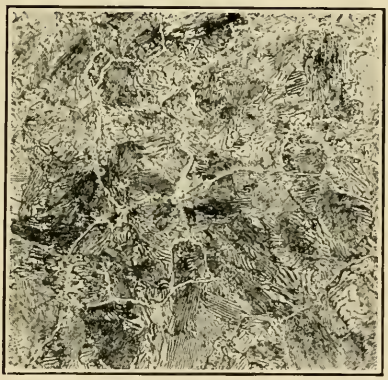


FIG. 79

FIG. 77. Steel. Annealed. 1.10% carbon. Lamellar-pearlite grains surrounded by a fine membrane of cementite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 78. Steel. Annealed. 1.25% carbon. Pearlite grains surrounded by a membrane of cementite. Etched in 5% Nital. 100×.

FIG. 79. Same as in Fig. 78. More highly magnified. 250×. Original magnification, 500×.

NORMALIZED HOT-ROLLED STEEL

Figs. 80-83 inclusive

NORMALIZED HOT-ROLLED STEEL

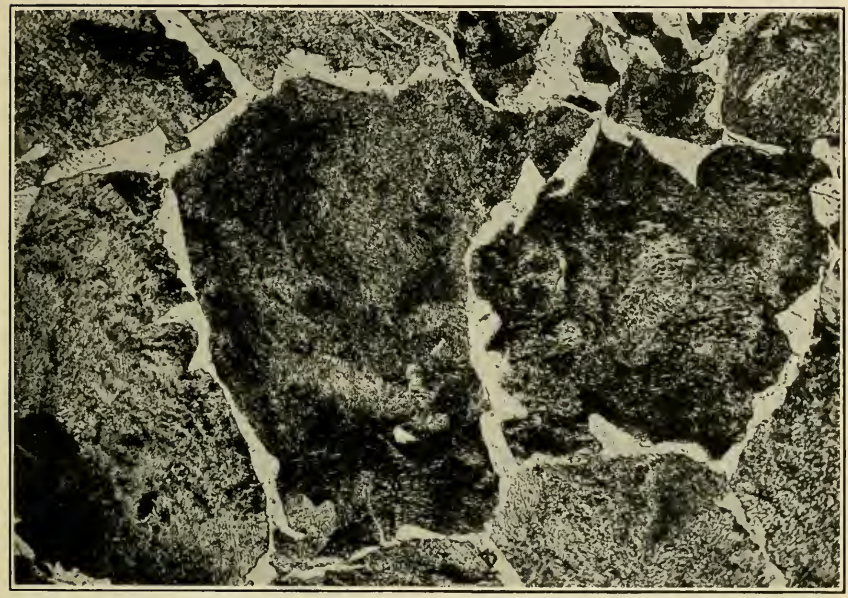


FIG. 80

FIG. 80. Steel. Normalized. 0.50% carbon. Grains of sorbite surrounded by a membrane of ferrite. Etched in 5% Nital. 375×. Original magnification, 500×.

NORMALIZED HOT-ROLLED STEEL

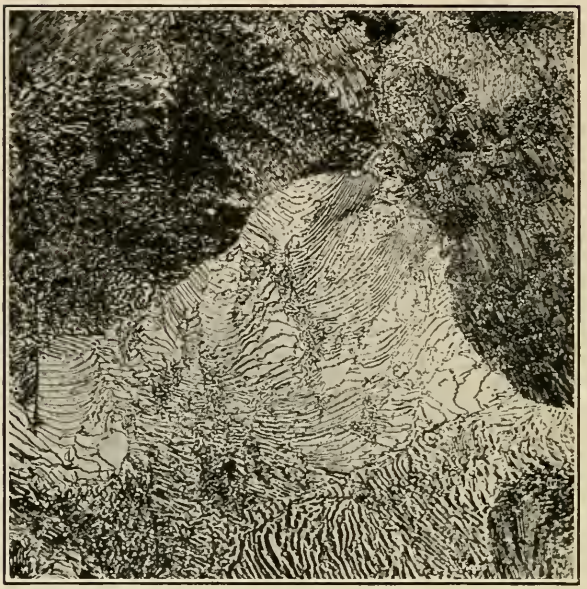


FIG. 81

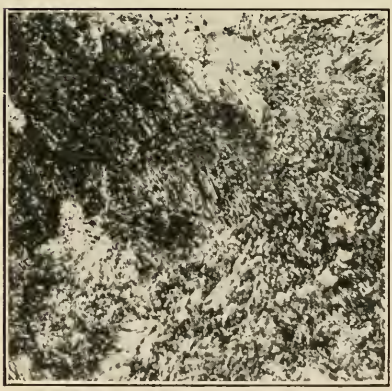


FIG. 82

FIG. 83

FIG. 81. Steel. Normalized. 0.85% carbon. Sorbito-pearlite. Etched in 5% Nital. 375×. Original magnification, 500×.

FIG. 82. Steel. Normalized. 0.85% carbon. Sorbite. Etched in 5% Nital. 500×.

FIG. 83. Steel. Normalized. 1.25% carbon. Sorbite and cementite. Etched in 5% Nital. 500×.

HARDENED HOT-ROLLED STEEL

Figs. 84-90 inclusive

HARDENED HOT-ROLLED STEEL

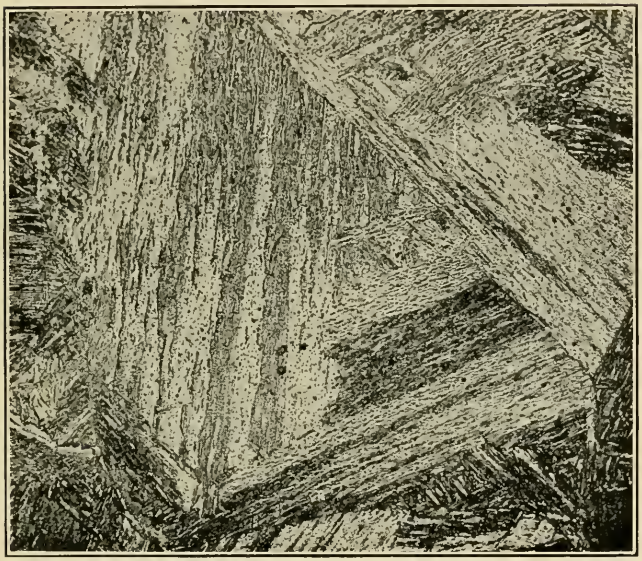


FIG. 84

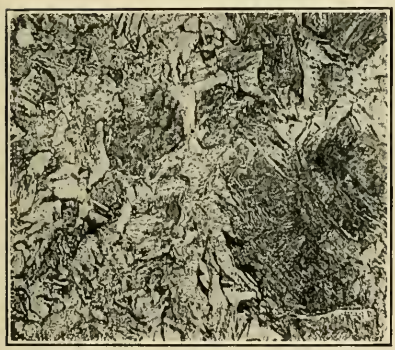


FIG. 85

FIG. 86

FIG. 84. Steel. 0.08% carbon. Heated to a temperature considerably above the critical range and quenched in water. Martensite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 85. Steel. 0.15% carbon. Heated to 926° C. and quenched in water. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 86. Steel. 0.30% carbon. Heated to 883° C. and quenched in water. Etched in 5% Nital. 250×. Original magnification, 500×.

HARDENED HOT-ROLLED STEEL

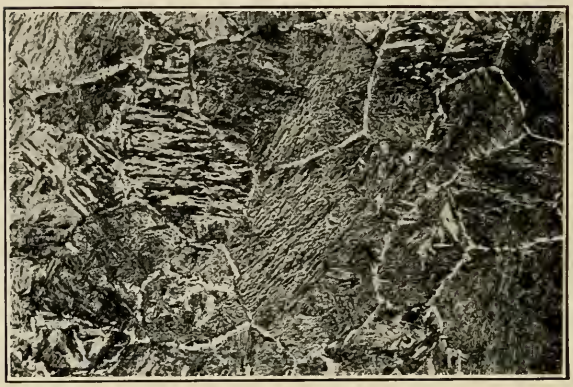


FIG. 87

FIG. 88

FIG. 87. Steel. 0.30% carbon. Heated to a temperature considerably above the critical temperature and quenched in water. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 88. Steel. 0.50% carbon. Heated to 840° C. and quenched in water. Martensite. Etched in 5% Nital. 500×.

HARDENED HOT-ROLLED STEEL

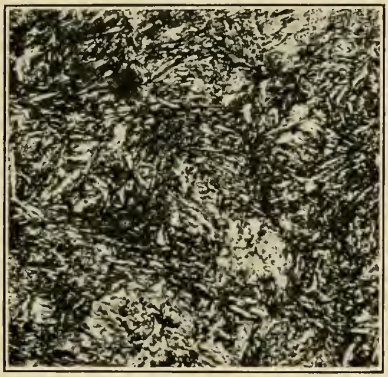


FIG. 89

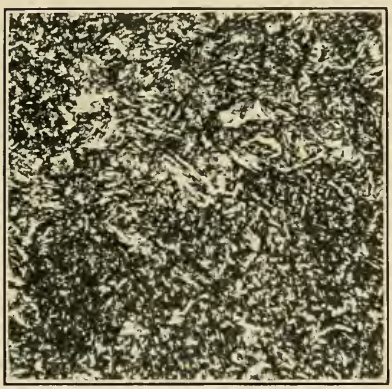


FIG. 90

FIG. 89. Steel. 0.85% carbon. Heated to 800° C. and quenched in water. Fine martensite. Etched in 5% Nital. 500×.

FIG. 90. Steel. 1.25% carbon. Heated to 776° C. and quenched in water Fine martensite. Etched in 5% Nital. 500×.

HARDENED AND TEMPERED HOT-ROLLED STEEL

Figs. 91 and 92

HARDENED AND TEMPERED HOT-ROLLED STEEL

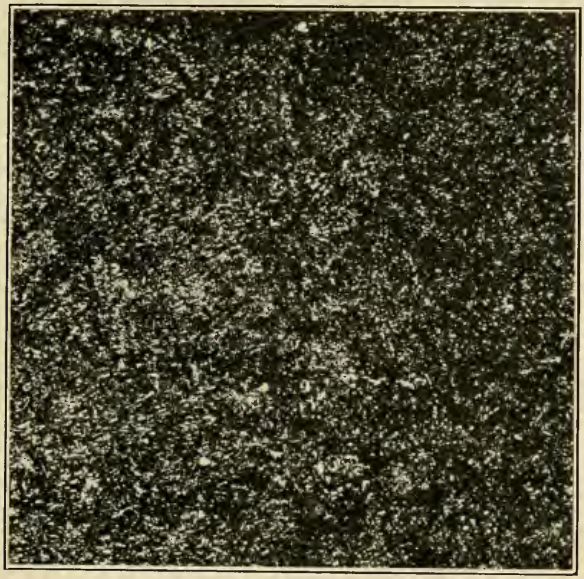


FIG. 91

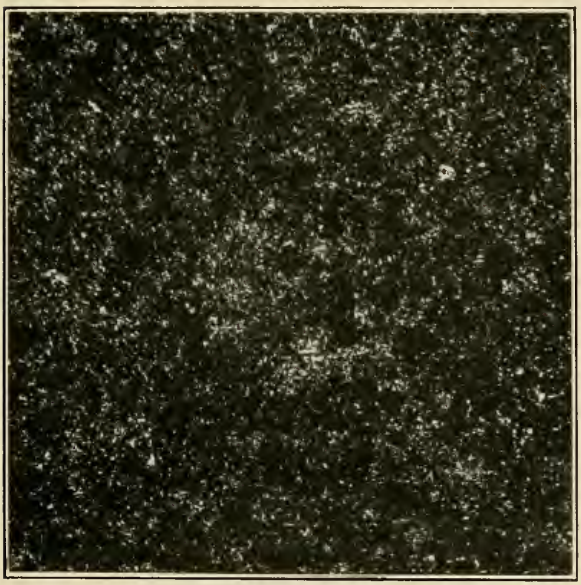


FIG. 92

FIG. 91. Steel. 0.85% carbon. Heated to 800° C. and quenched in oil; tempered at 400° C. and quenched in oil. Troostite. Etched in 5% Nital. 500×.

FIG. 92. Steel. 1.25% carbon. Heated to 776° C. and quenched in oil; tempered at 400° C. and quenched in oil. Troostite. Etched in 5% Nital. 500×.

HARDENED AND DRAWN HOT-ROLLED STEEL

Figs. 93-96 inclusive

HARDENED AND DRAWN HOT-ROLLED STEEL

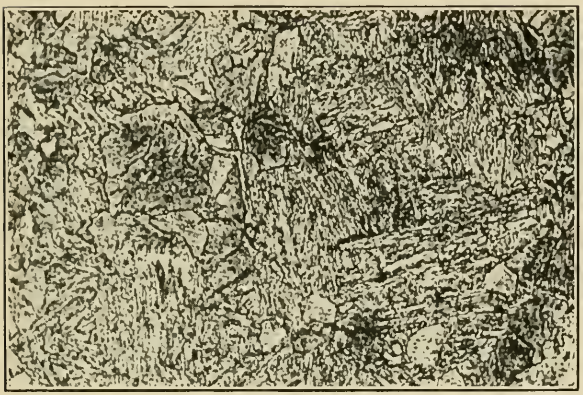


FIG. 93

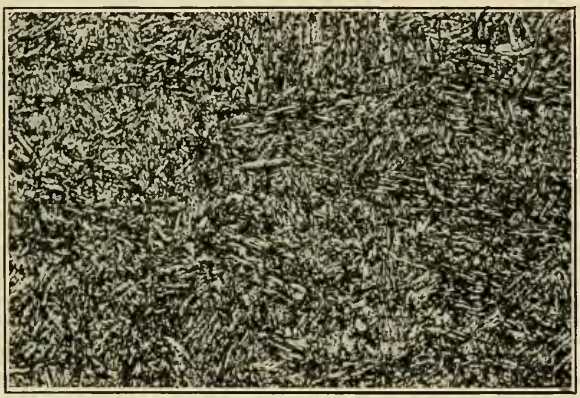


FIG. 94

FIG. 93. Steel. 0.35% carbon. Heated to 912° C. and cooled in air; reheated to 842° C. and quenched in water. Drawn at 532° C. and quenched in oil. S. A. E. Steel No. 1035 after recommended heat treatment VII. Sorbite. Etched in 5% Nital. 500×.

FIG. 94. Steel. 0.50% carbon. Heated to 850° C. and quenched in oil. Drawn at 600° C. and quenched in oil. S. A. E. Steel No. 1050 after recommended heat treatment VIII. Sorbite. Etched in 5% Nital. 500×.

HARDENED AND DRAWN HOT-ROLLED STEEL

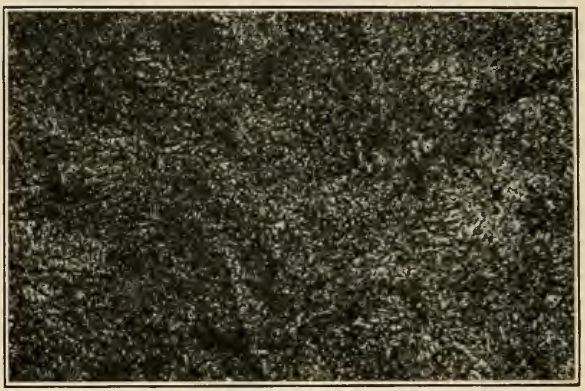


FIG. 95

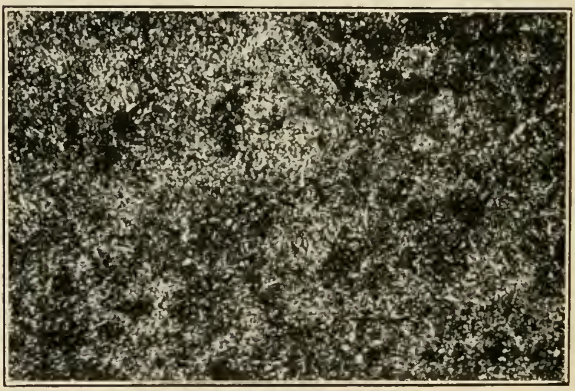


FIG. 96

FIG. 95. Steel. 0.85% carbon. Heated to 800° C. and quenched in oil. Drawn at 600° C. and quenched in oil. Sorbite. Etched in 5% Nital. 500×.

FIG. 96. Steel. 1.25% carbon. Heated to 776° C. and quenched in oil. Drawn at 600° C. and quenched in oil. Sorbite and small particles of cementite. Etched in 5% Nital. 500×.

STUDY OF TRANSITION CONSTITUENTS ACCORDING TO THE METCALF TEST

Figs. 97-124 inclusive

Figs. 97–105 represent a series of photomicrographs showing the transition constituents of a bar of 0.50% carbon steel heated to a very high temperature at one end, followed by quenching the entire bar in water.

Figs. 106–112 represent a series of photomicrographs showing the transition constituents of a bar of 0.85% carbon steel heated to a very high temperature at one end, followed by quenching the entire bar in water.

Figs. 113–124 represent a series of photomicrographs showing the transition constituents of a bar of 1.40% carbon steel heated to a very high temperature at one end, followed by quenching the entire bar in water.

TRANSITION CONSTITUENTS — METCALF TEST

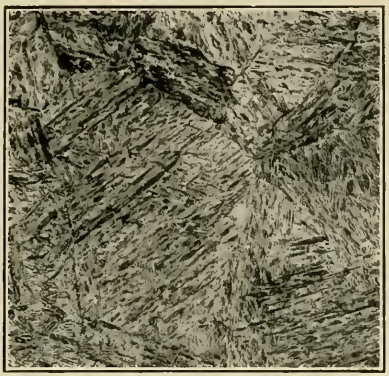


FIG. 97

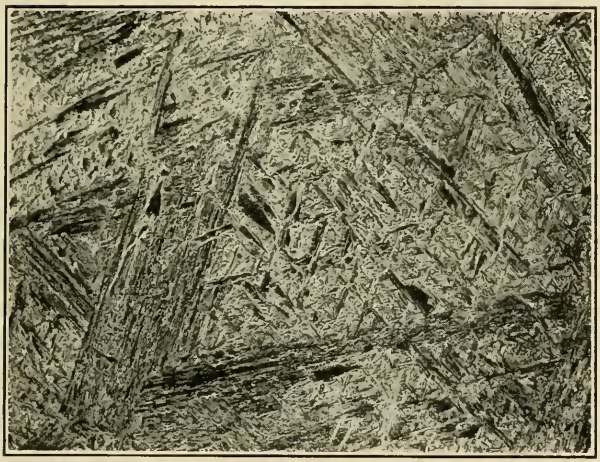


FIG. 98

FIG. 97. Steel. 0.50% carbon. Microstructure of the bar after heating to a temperature exceeding the critical range and quenching in water. Martensite and also the persistence of austenitic grain boundaries. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 98. Steel. 0.50% carbon. Microstructure of the bar after heating to a temperature exceeding the critical range and quenching in water. Martensite. Etched in 5% Nital. 250×. Original magnification, 500×.

TRANSITION CONSTITUENTS — METCALF TEST

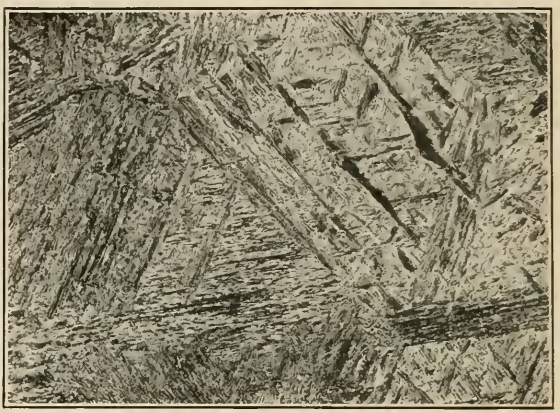


FIG. 99

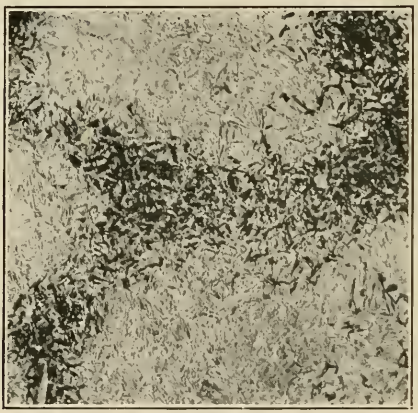


FIG. 100

FIG. 99. Steel. 0.50% carbon. Microstructure of portion of the bar heated to a temperature exceeding the critical range and quenching in water. Martensite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 100. Steel. 0.50% carbon. Microstructure of portion of the bar heated to a temperature exceeding the critical range and quenching in water. Troostite surrounding martensite grains. Etched in 5% Nital. 250×. Original magnification, 500×.

TRANSITION CONSTITUENTS — METCALF TEST

FIG. 101

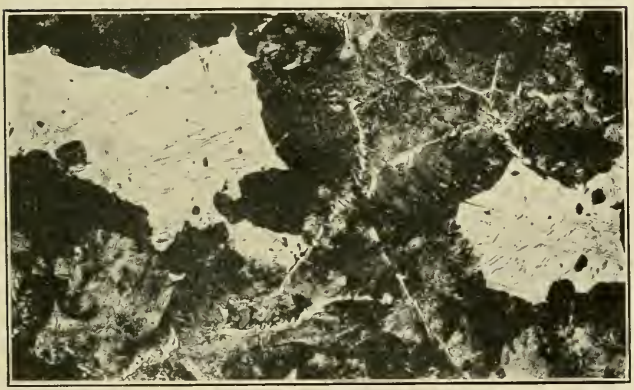


FIG. 102

FIG. 101. Steel. 0.50% carbon. Microstructure of portion of the bar heated to a temperature within the critical range and quenched in water. Troostite surrounding martensite grains with particles of ferrite embedded in troostite areas. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 102. Steel. 0.50% carbon. Microstructure of another portion of the bar heated to a temperature within the critical range and quenched in water. The two large grains, the boundaries of which are ferrite, consist of martensitic areas, surrounded by troostito-sorbite. Etched in 5% Nital. 250×. Original magnification, 500×.

TRANSITION CONSTITUENTS — METCALF TEST

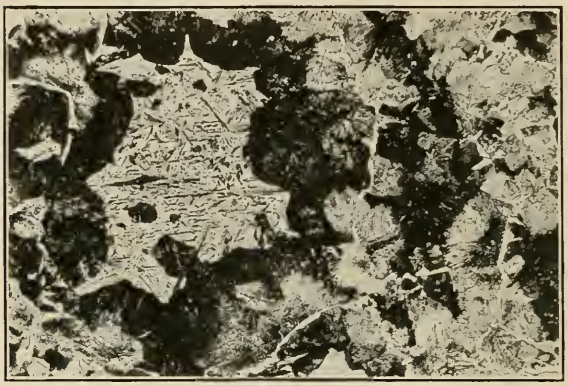


FIG. 103

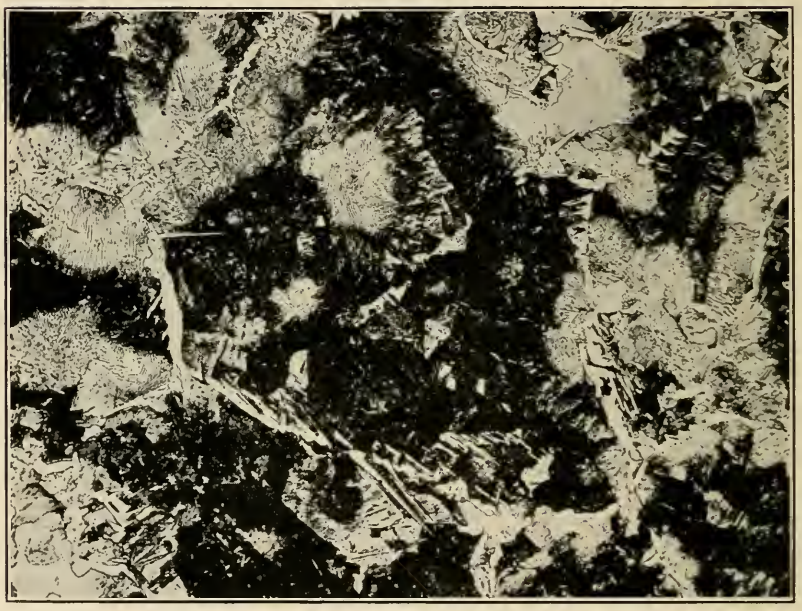


FIG. 104

FIG. 103. Steel. 0.50% carbon. Microstructure of portion of the bar heated to a temperature within the critical range and quenched in water. A series of transition constituents, namely, martensite, troostite, troostito-sorbite, pearlite and ferrite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 104. Steel. 0.50% carbon. Microstructure of portion of the bar heated to a temperature within the critical range and quenched in water. A series of transition constituents, namely, troostito-sorbite, pearlite and ferrite. Etched in 5% Nital. 250×. Original magnification, 500×.

TRANSITION CONSTITUENTS — METCALF TEST

FIG. 105

FIG. 105. Steel. 0.50% carbon. Microstructure of portion of the bar which was heated to a temperature below the critical range and quenched in water. A grain of pearlite, the constituents of which are arranged in a Widmanstätten or cleavage pattern. Etched in 5% Nital. 750×. Original magnification, 1000×.

TRANSITION CONSTITUENTS — METCALF TEST

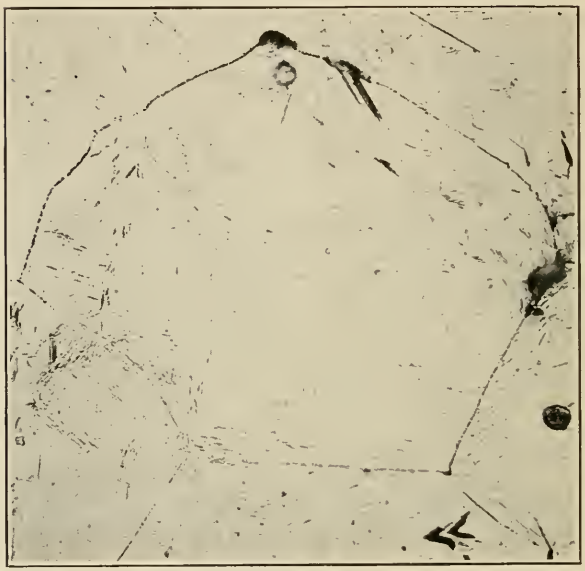


Fig. 106

Fig. 106. Steel. 0.85% carbon. Microstructure of a portion of the bar heated to a temperature near the melting point and quenched in water. Original austenitic pattern, — the matrix of which is finely martensitic. Etched in 5% Nital. 375×. Original magnification, 500×.

TRANSITION CONSTITUENTS — METCALF TEST

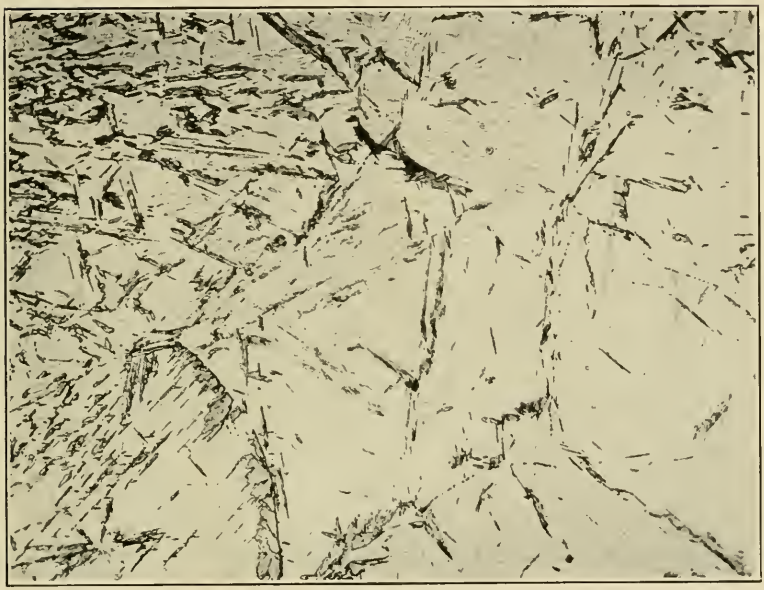


FIG. 107

FIG. 107. Steel. 0.85% carbon. Microstructure of a portion of the bar heated to a temperature considerably above the critical range and quenched in water. Austenito-martensite. Etched in 5% Nital. 375×. Original magnification, 500×.

TRANSITION CONSTITUENTS — METCALF TEST

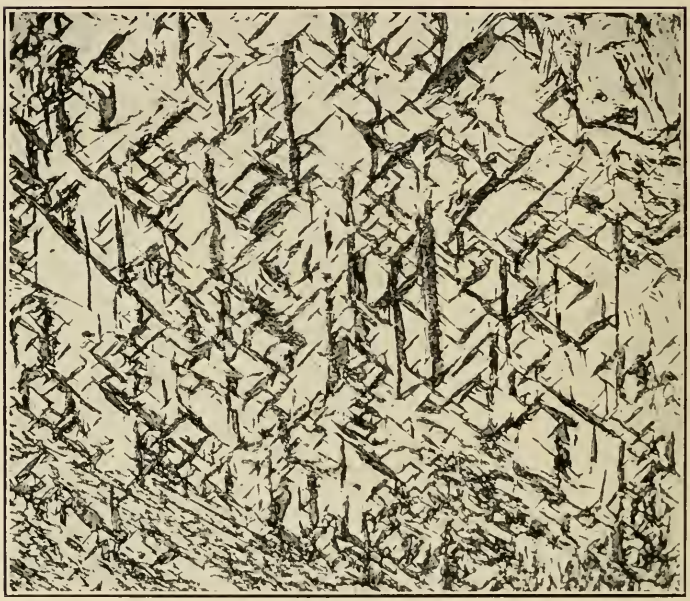


FIG. 108

FIG. 108. Steel. 0.85% carbon. Microstructure of portion of the bar heated to a temperature considerably above the critical range and quenched in water. Austenito-martensite. The transformation of austenite to martensite took place along the octahedral cleavage planes. Etched in 5% Nital. 375×. Original magnification, 500×.

TRANSITION CONSTITUENTS — METCALF TEST

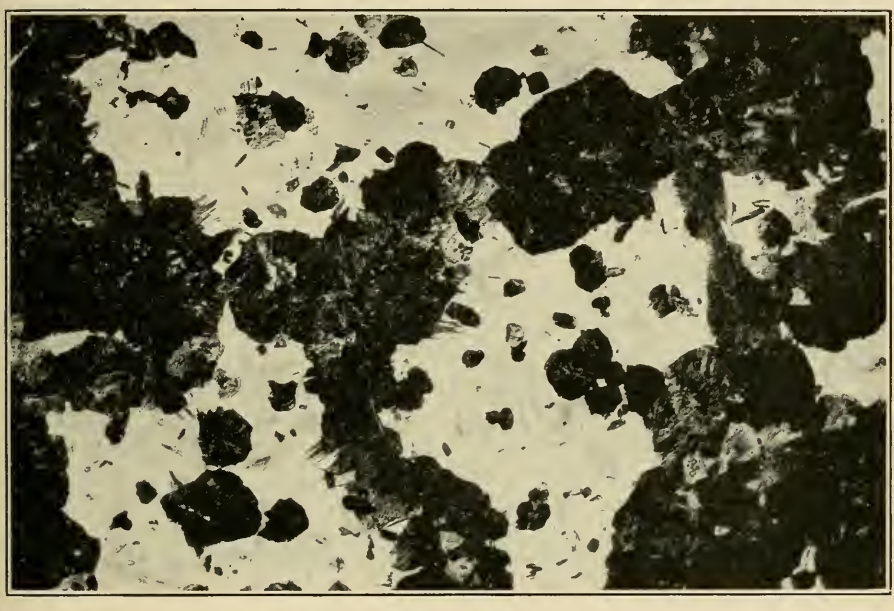


Fig. 109

Fig. 109. Steel. 0.85% carbon. Microstructure of portion of bar heated to a temperature considerably above the critical range and quenched in water. Troostito-martensite. Etched in 5% Nital. 375×. Original magnification, 500×.

TRANSITION CONSTITUENTS — METCALF TEST

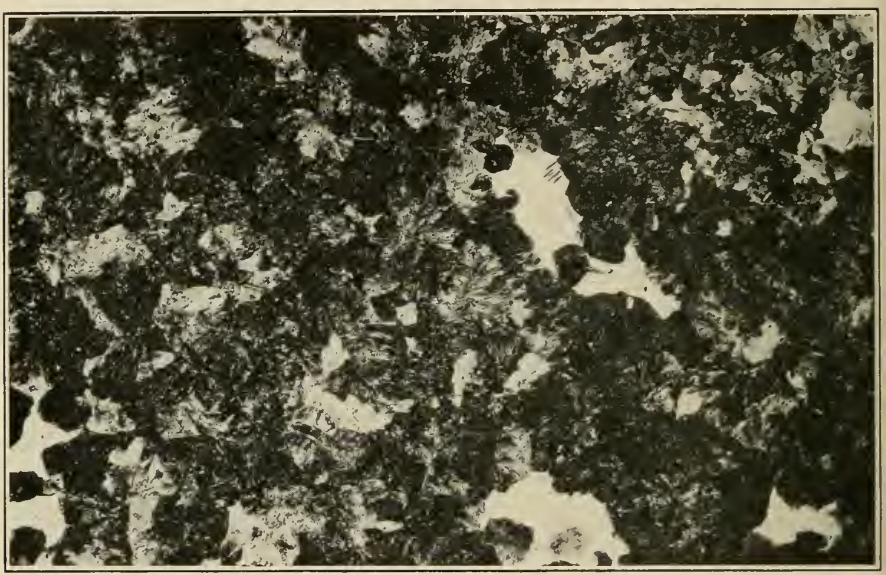


Fig. 110

Fig. 110. Steel. 0.85% carbon. Microstructure of portion of bar heated to a temperature within the critical range and quenched in water. Troostite and small areas of martensite. Etched in 5% Nital. 375×. Original magnification, 500×.

TRANSITION CONSTITUENTS — METCALF TEST

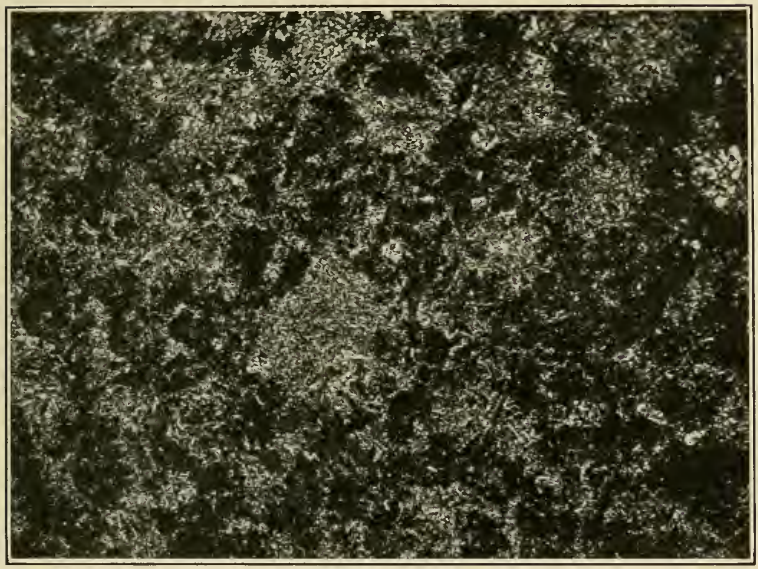


FIG. 111

FIG. 111. Steel. 0.85% carbon. Microstructure of portion of the bar heated to a temperature within the critical range and quenched in water. Troostite and sorbite. Etched in 5% Nital. 375×. Original magnification, 500×.

TRANSITION CONSTITUENTS — METCALF TEST

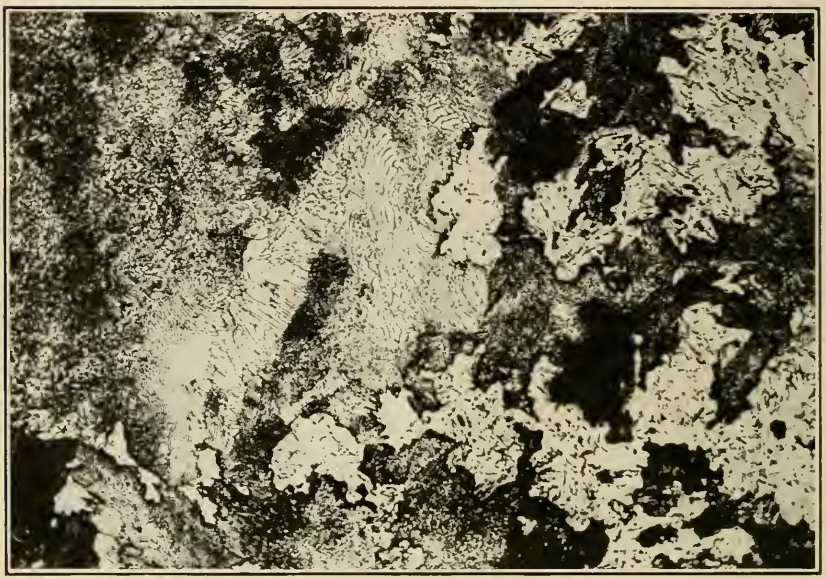


Fig. 112

Fig. 112. Steel. 0.85% carbon. Microstructure of portion of the bar heated to a temperature within the critical range and quenched in water. Transition constituents, namely, martensite areas bounded by troostite, sorbite, and pearlite. Etched in 5% Nital. 375×. Original magnification, 500×.

TRANSITION CONSTITUENTS — METCALF TEST

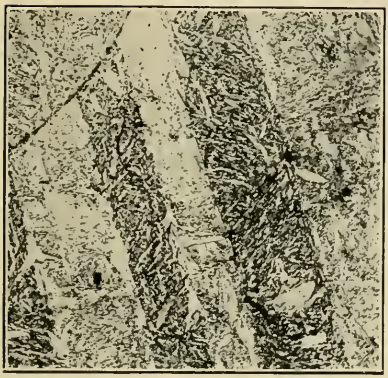


FIG. 113

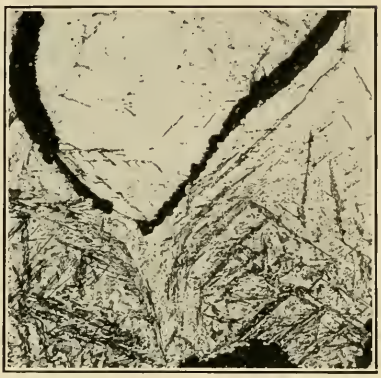


FIG. 114

FIG. 115

FIG. 113. Steel. 1.40% carbon. Microstructure of portion of the bar heated to a temperature considerably above the critical range and quenched in water. The original twinning pattern in the austenite grain is preserved. Matrix of martensite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 114. Steel. 1.40% carbon. Microstructure of portion of the bar heated to a temperature considerably above the critical range and quenched in water. Troostite precipitated along the original austenite grain boundary, the matrix, being martensite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 115. Steel. 1.40% carbon. Microstructure of portion of the bar heated to a temperature considerably above the critical range and quenched in water. Martensite. Etched in 5% Nital. 250×. Original magnification, 500×.

TRANSITION CONSTITUENTS — METCALF TEST

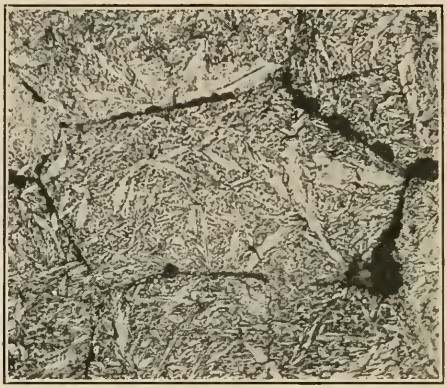


FIG. 116

FIG. 117

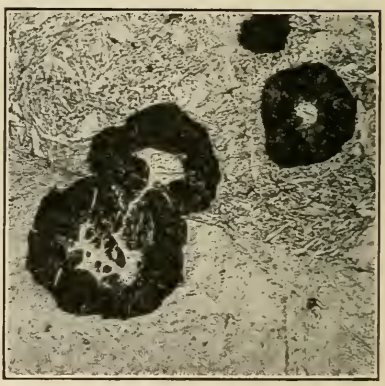


FIG. 118

FIG. 116. Steel. 1.40% carbon. Microstructure of portion of the bar heated to a temperature considerably above the critical range and quenched in water. Troostite precipitated along the original austenite grain boundaries. Matrix of austenite. Etched in 5% Nital. Original magnification, 500×.

FIG. 117. Steel. 1.40% carbon. Microstructure of portion of the bar heated to a temperature considerably above the critical range and quenched in water. Troostite and martensite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 118. Steel. 1.40% carbon. Microstructure of portion of the bar heated to a temperature below the Acm point and quenched in water. Cementite surrounded by troostite areas in martensite matrix. Etched in 5% Nital. 250×. Original magnification, 500×.

TRANSITION CONSTITUENTS — METCALF TEST

FIG. 119

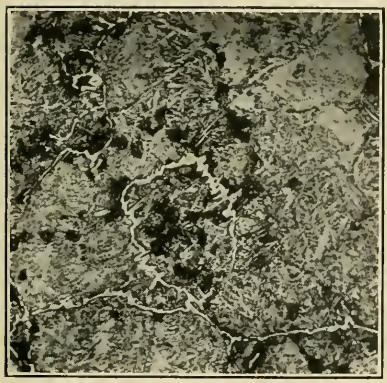


FIG. 120

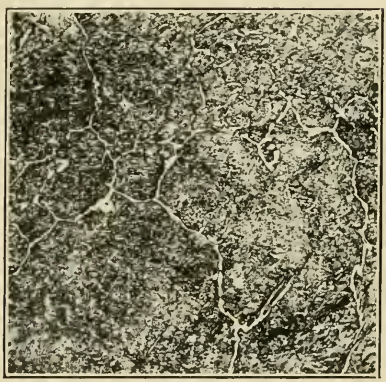


FIG. 121

FIG. 119. Steel. 1.40% carbon. Microstructure of portion of the bar heated to a temperature below the Acm point and quenched in water. Cementite in martensitic matrix. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 120. Steel. 1.40% carbon. Microstructure of portion of the bar heated to a temperature within the critical range and quenched in water. Cementite network, troostite and martensite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 121. Steel. 1.40% carbon. Microstructure of portion of the bar heated to a temperature below the Acm point and quenched in water. Free cementite surrounding grains composed of fine martensite. Etched in 5% Nital. 250×. Original magnification, 500×.

TRANSITION CONSTITUENTS — METCALF TEST

FIG. 122

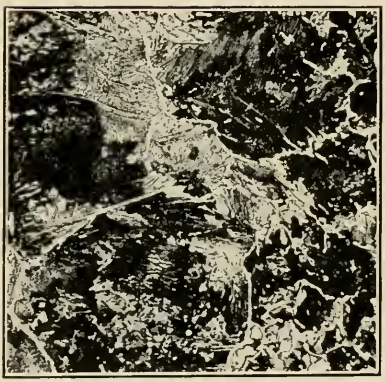


FIG. 123

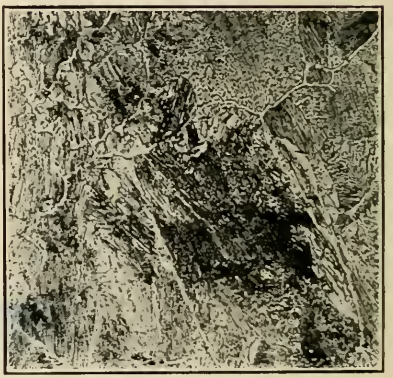


FIG. 124

FIG. 122. Steel. 1.40% carbon. Microstructure of portion of the bar heated to a temperature below the Acm point. Cementite network, troostite and martensite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 123. Steel. 1.40% carbon. Microstructure of portion of the bar heated to a temperature within the critical range and quenched in water. Cementite network, surrounding grains made up of martensite, troostito-sorbite and pearlite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 124. Steel. 1.40% carbon. Microstructure of portion of the bar heated to a temperature below the critical range and quenched in water. Cementite and pearlite. Etched in 5% Nital. 250×. Original magnification, 500×.

SPHEROIDIZED STEEL

Figs. 125 and 126

SPHEROIDIZED STEEL

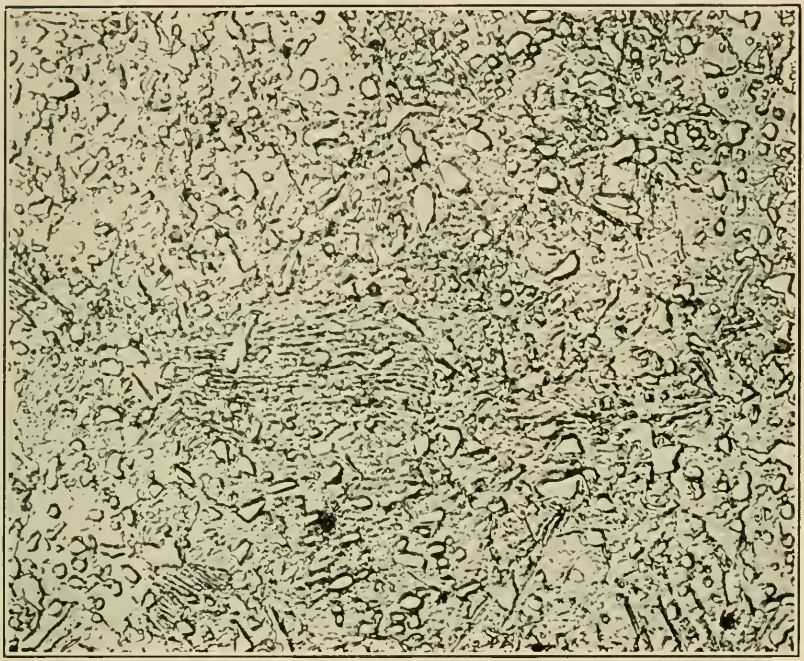


FIG. 125

FIG. 125. Steel. 1.10% carbon. Partially spheroidized steel. Heated to a temperature above the critical range, quenched in water, reheated 7 hours at 700° C., and cooled in furnace. Globules of cementite in matrix of ferrite with occasional trace of pearlite. Etched in 5% Nital. 750×. Original magnification, 1000×.

SPHEROIDIZED STEEL

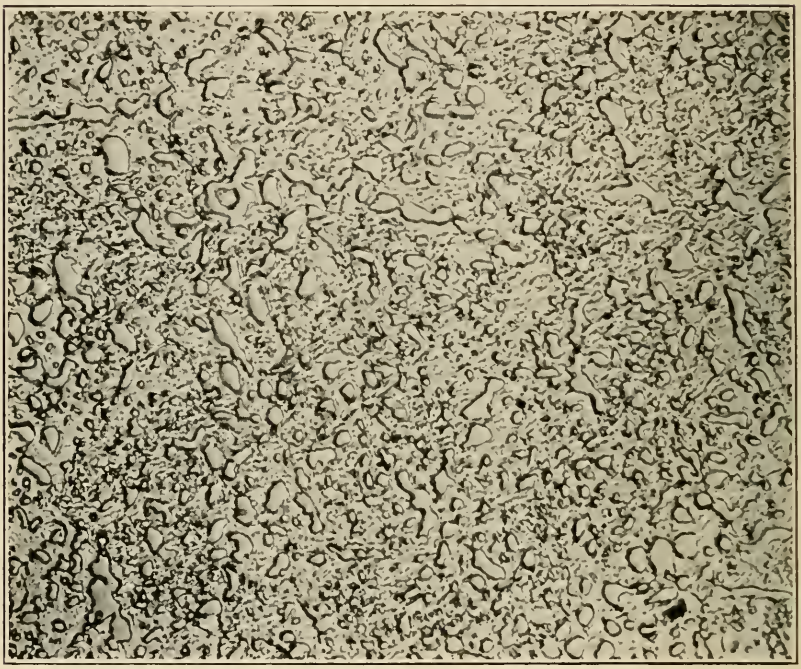


FIG. 126

FIG. 126. Steel. 1.10% carbon. Fully spheroidized steel. Heated to a temperature above the critical range, quenched in water, reheated 7 hours at 700° C., and cooled in furnace. Globules of cementite in matrix of ferrite. Etched in 5% Nital. 750×. Original magnification, 1000×.

GRAPHITIZED CEMENTITE

Figs. 127 and 128

GRAPHITIZED CEMENTITE

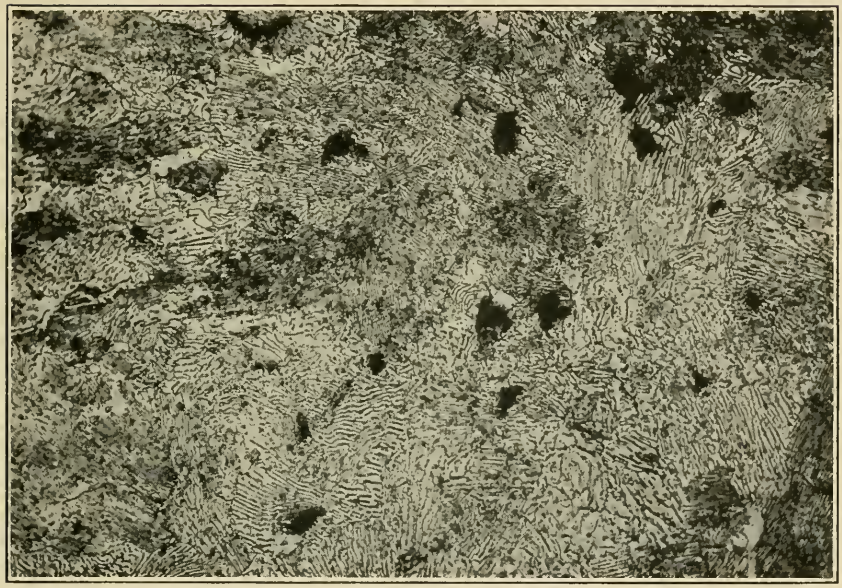


FIG. 127

FIG. 127. Steel. 1.10% carbon. Partially graphitized cementite. Heated 1 hour at 1000° C. and cooled in furnace. Temper carbon and pearlite. Etched in 5% Nital. 375×. Original magnification, 500×.

GRAPHITIZED CEMENTITE

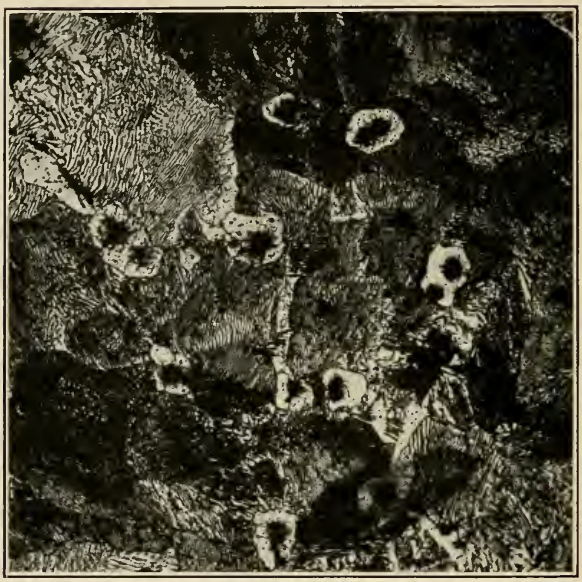


FIG. 128

FIG. 128. Steel. 1.10% carbon. Graphitized cementite. Heated 2 hours at 1050° C. and cooled in furnace. Temper carbon surrounded by ferrite areas in grains of sorbito-pearlite. Etched in 5% Nital. 375×. Original magnification, 500×.

OVERHEATED AND BURNT STEEL

Figs. 129 and 130

OVERHEATED AND BURNT STEEL

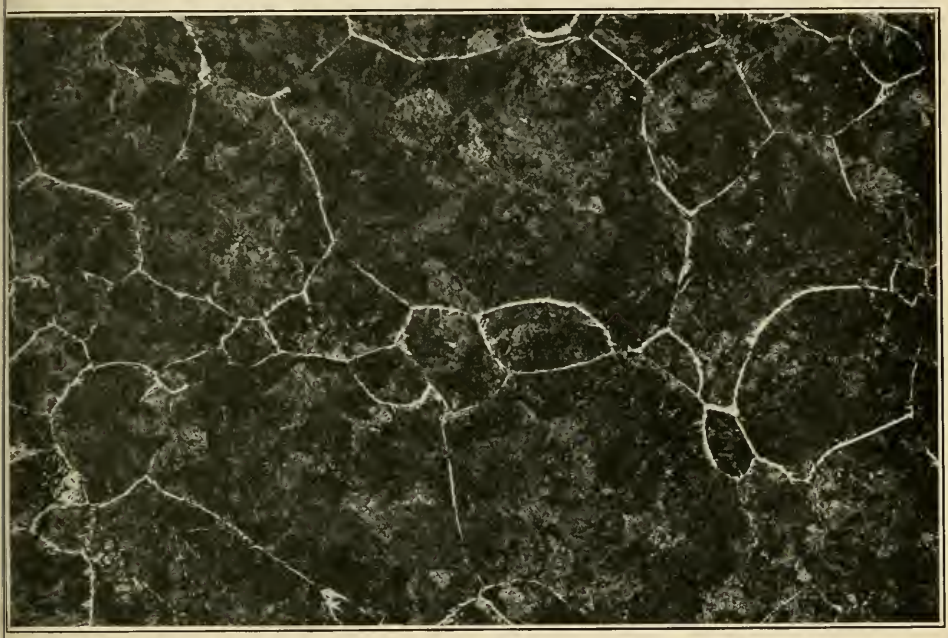


FIG. 129

FIG. 129. Steel. 0.50% carbon. Overheated steel. Heated for 5 hours at 1100° C., and cooled in furnace. Large grains of sorbito-pearlite surrounded by a membrane of ferrite. Etched in 5% Nital. 75×. Original magnification, 100×.

OVERHEATED AND BURNT STEEL

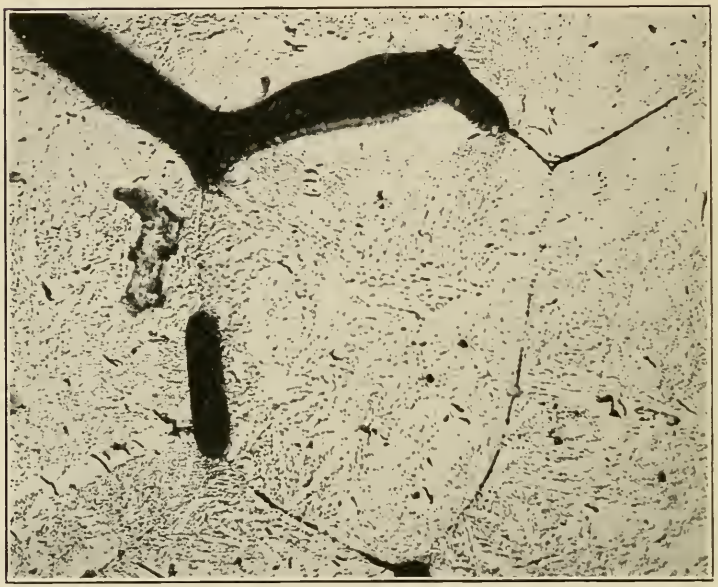


FIG. 130

FIG. 130. Steel. 1.25% carbon. Burnt steel. Heated to a sintering heat and quenched in water. The grain boundaries of the metal have been badly oxidized. Lightly etched in 5% Nital. 375×. Original magnification, 500×.

GRAIN GROWTH IN MILD STEEL

Figs. 131-133 inclusive

GRAIN GROWTH IN MILD STEEL

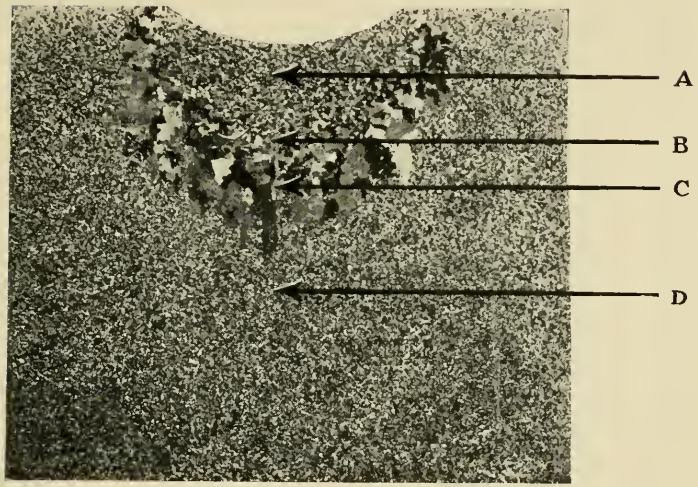


Fig. 131

Fig. 131. Steel. 0.08% carbon. Subjected to Brinell Ball test under a pressure of 3000 kilograms, heated 7 hours at 650° C., and cooled slowly in furnace. Vertical section through bottom of spherical depression. Etched in 12% Nital. 5.5×.

A — Metal too severely strained to grow.
B — Junction between critically strained and unstrained metal.
C — Critically strained metal.
D — Unstrained metal.

GRAIN GROWTH IN MILD STEEL

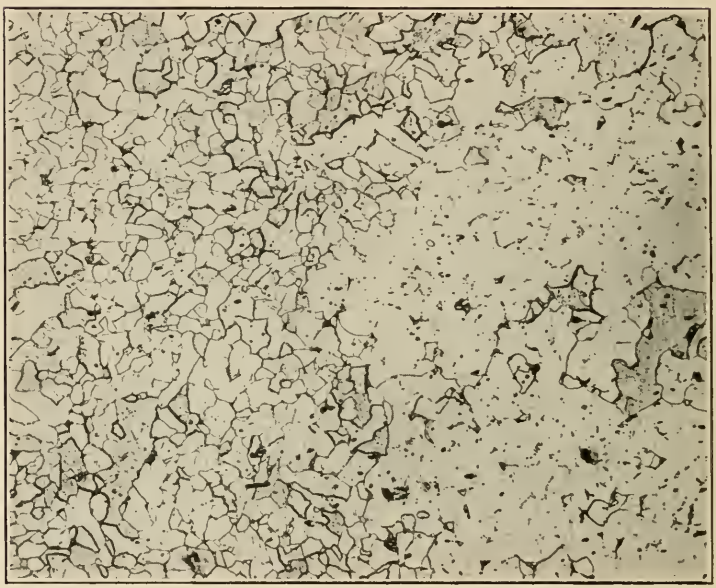


FIG. 132

FIG. 132. Steel. 0.08% carbon. Grain growth in low carbon steel. Microstructure at Section B shown in Fig. 131 illustrates junction between critically strained and unstrained metal. Etched in 5% Nital. 75×. Original magnification, 100×.

GRAIN GROWTH IN MILD STEEL

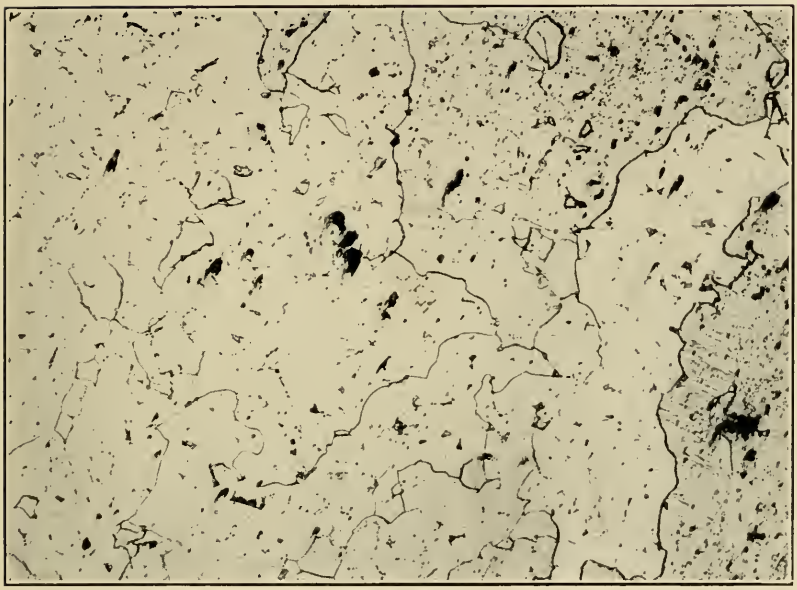


FIG. 133

FIG. 133. Steel. 0.08% carbon. Grain growth in low carbon steel. Microstructure at Section C shown in Fig. 131 illustrates critically strained material. Etched in 5% Nital. 75×. Original magnification, 100×.

CASE-HARDENED CARBON STEEL

AND

HEAT TREATED CASE-HARDENED CARBON STEEL

Figs. 134-142 inclusive

CASE-HARDENED CARBON STEEL

Fig. 134

Fig. 135

Fig. 134. Steel. 0.15% carbon. Case-hardened with eutectoid case. Specimen cooled slowly in box after case-hardening. Etched in 5% Nital. 50×. Original magnification, 100×.

Fig. 135. Steel. 0.15% carbon. Heat treated case-hardened 0.15% carbon steel (same steel as shown in Fig. 134). Heated to 980° C., and quenched in water to refine core; heated to 825° C., and quenched in water to refine case. Etched in 5% Nital 50×. Original magnification, 100×.

CASE-HARDENED CARBON STEEL

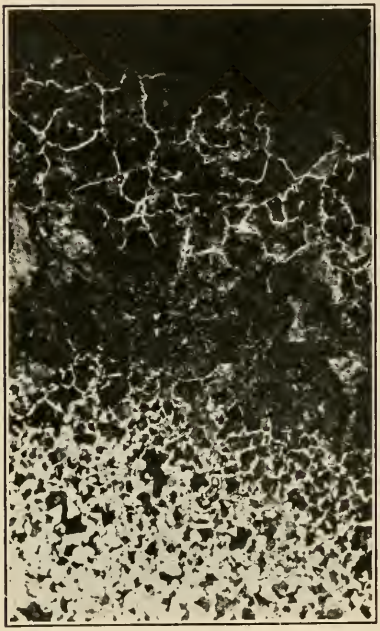


FIG. 136

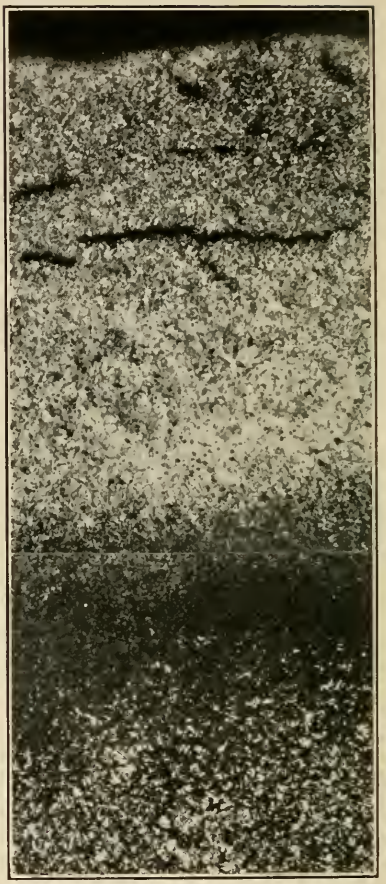


FIG. 137

FIG. 136. Steel. 0.15% carbon. Case-hardened. Free cementite in case. Cooled slowly from case-hardening treatment. Etched in 5% Nital. 50×. Original magnification, 100×.

FIG. 137. Steel. 0.15% carbon. Heat treated case-hardened steel. (Same steel as shown in Fig. 136.) Heated to 980° C., and quenched in water to refine the core. Heated to 825° C., and quenched in water to refine the case. The presence of free cementite in the case caused cracks to develop during the quenching operation. Etched in 5% Nital. 50×. Original magnification, 100×.

CASE-HARDENED CARBON STEEL

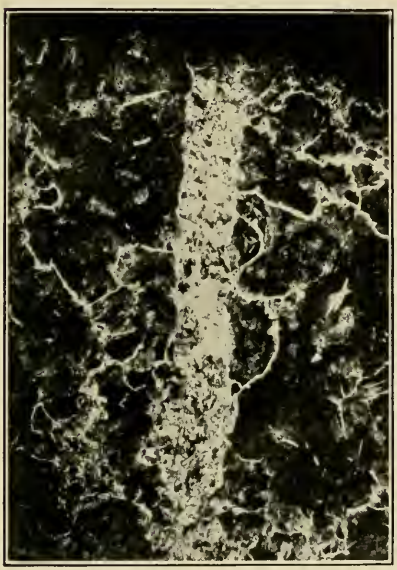
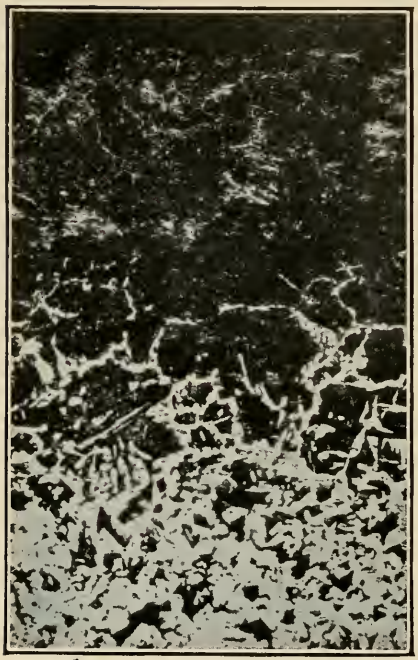


FIG. 138

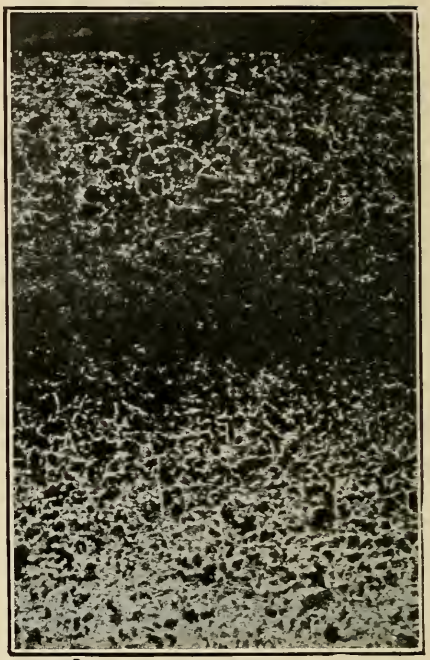
FIG. 138. Steel. Case-hardened. Example of phosphorus segregation in case of hyper-eutectoid composition. The phosphorus rich area has not absorbed carbon during the carburizing process. Etched in 5% Nital. 50×. Original magnification, 100×.

CASE-HARDENED CARBON STEEL



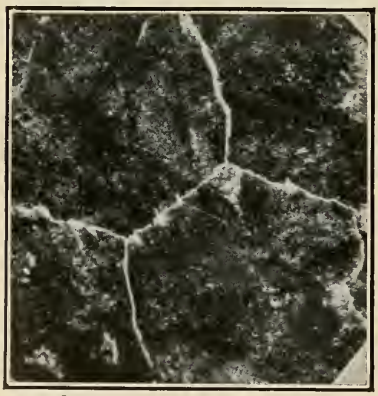
1

Fig. 139



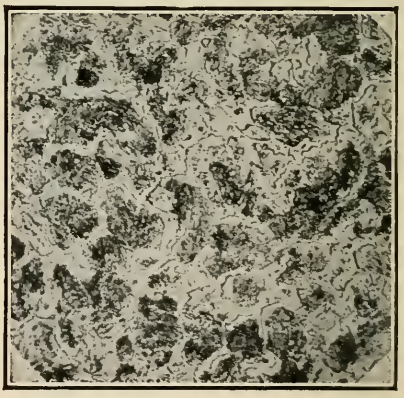
2

Fig. 140



3

Fig. 141



4

Fig. 142

Fig. 139. Case of normal steel. Will give a martensitic case in hardening. Magnified 50 diameters.

Fig. 140. Case of abnormal steel. Will give soft troostitic spots in hardening. Magnified 50 diameters.

Fig. 141. Hyper-eutectoid zone of normal steel. Magnified 200 diameters.

Fig. 142. Hyper-eutectoid zone of abnormal steel. Magnified 200 diameters. (E. W. Ehn.) Reproduced from Sauveur's Metallography and Heat Treatment of Iron and Steel by permission.

DECARBURIZED STEEL

Fig. 143

DECARBURIZED STEEL

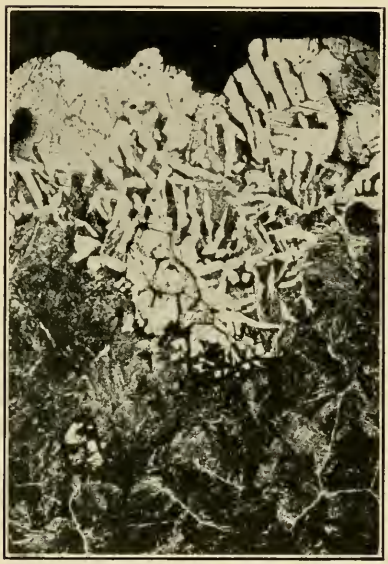


FIG. 143

FIG. 143. Steel. 1.40% carbon. Decarburized. Heated 5 hours at a temperature considerably above the critical range and slowly cooled in furnace. The edge of the specimen is practically carbonless. Etched in 5% Nital. 50×. Original magnification, 100×.

ALLOY STEEL

A. NICKEL STEEL

Cast, forged, annealed and after recommended heat treatment

Figs. 144-148 inclusive

ALLOY STEEL — NICKEL STEEL

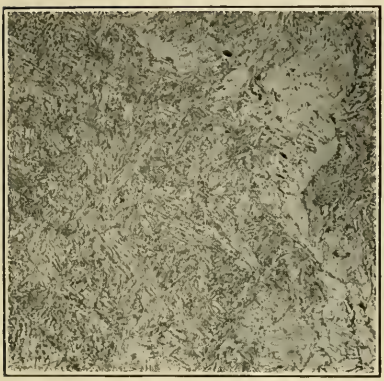


FIG. 144

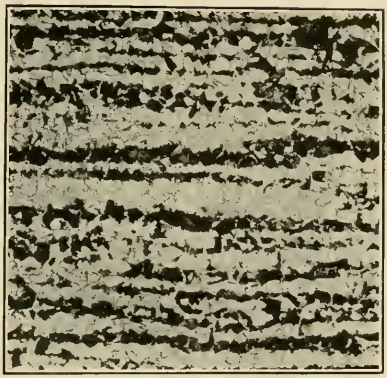


FIG. 145

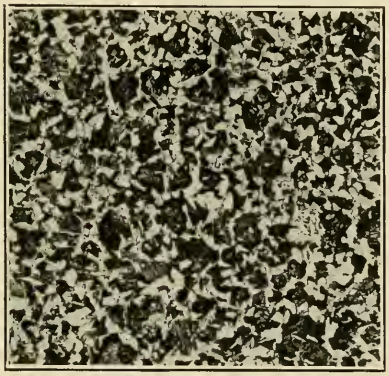


FIG. 146

FIG. 144. Nickel steel. Cast. 0.30% carbon; 3.50% nickel. Fine Widmanstätten structure. Etched in 5% Nital. 50×. Original magnification, 100×.

FIG. 145. Nickel steel. Hot-rolled. 0.30% carbon; 3.50% nickel. Banded structure. Etched in 5% Nital. 50×. Original magnification, 100×.

FIG. 146. Nickel steel. Annealed. 0.30% carbon; 3.50% nickel. Etched in 5% Nital. 100×.

ALLOY STEEL — NICKEL STEEL

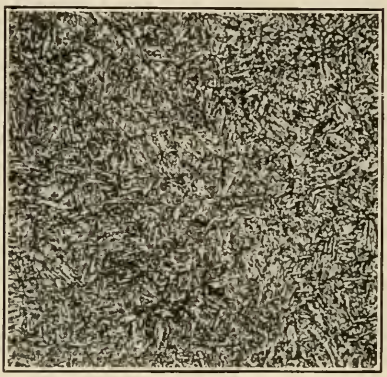


FIG. 147

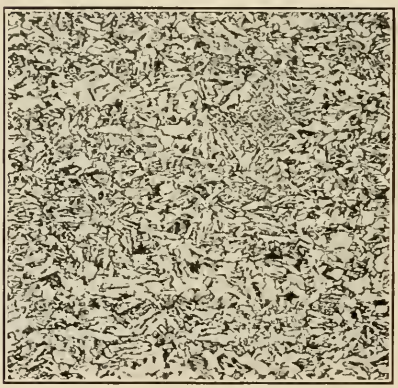


FIG. 148

FIG. 147. Nickel steel. Heat treated. 0.30% carbon; 3.50% nickel. Normalized at 913° C. Heated to 902° C., and quenched in oil. Drawn at 538° C. S. A. E. Steel No. 2330 after recommended heat treatment VII. Etched in 5% Nital. 500×.

FIG. 148. Nickel steel. Hot-rolled. 0.30% carbon; 5.00% nickel. Etched in 5% Nital. 100×.

B. CHROMIUM STEEL

Annealed and after recommended heat treatment

Figs. 149-154 inclusive

ALLOY STEEL — CHROMIUM STEEL

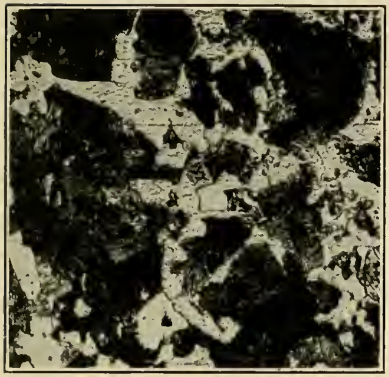


FIG. 149

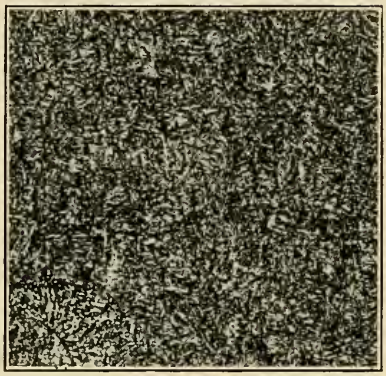


FIG. 150

FIG. 151

FIG. 149. Chromium steel. Annealed. 0.40% carbon; 0.95% chromium. S. A. E. Steel No. 5140 annealed. Etched in 5% Nital. 500×.

FIG. 150. Chromium steel. Heat treated. 0.40% carbon; 0.95% chromium. Normalized at 913° C., reheated to 843° C., quenched in oil. S. A. E. Steel No. 5140 after heat treatment VIII. Drawn at 538° C. Etched in 5% Nital. 500×.

FIG. 151. Chromium steel. Annealed. 1.00% carbon; 1.35% chromium. S. A. E. Steel No. 52100 annealed. Etched in 5% Nital. 500×.

ALLOY STEEL — CHROMIUM STEEL

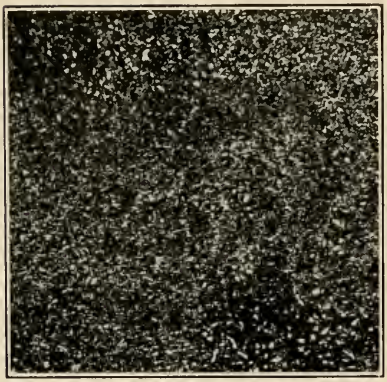


FIG. 152

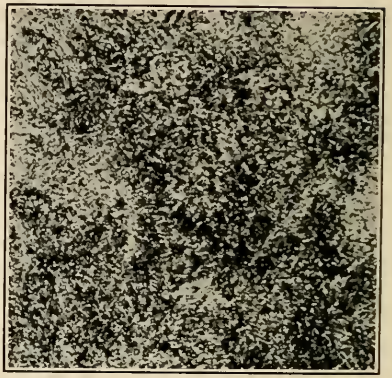


FIG. 153

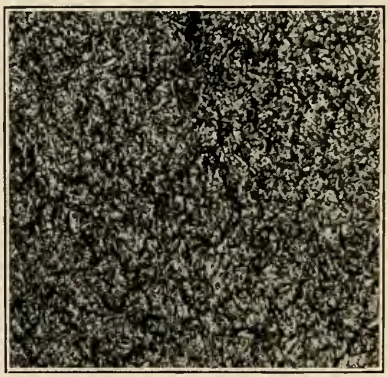


FIG. 154

FIG. 152. Chromium steel. Heat treated. 1.00% carbon; 1.35% chromium. Heated to 829° C., quenched in oil. Drawn at 538° C. S. A. E. Steel No. 52100 after recommended heat treatment VI. Etched in 5% Nital. 500×.

FIG. 153. Stainless steel. Annealed. 0.30% carbon; 12.00% chromium. Etched in Marble's reagent. 500×.

FIG. 154. Stainless steel. Hardened and tempered. 0.30% carbon; 12.00% chromium. Etched in Marble's reagent. 500×.

C. NICKEL-CHROMIUM STEEL

Annealed and after recommended heat treatment

Figs. 155-158 inclusive

ALLOY STEEL — NICKEL-CHROMIUM STEEL

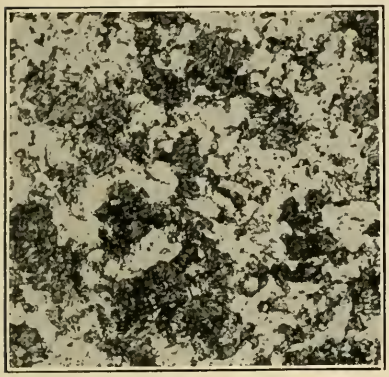


FIG. 155

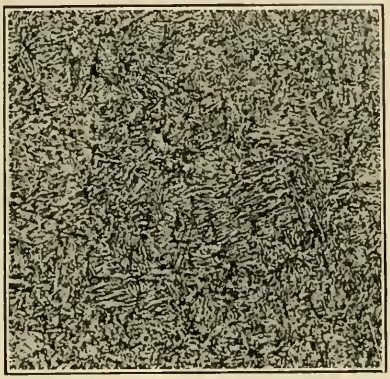


FIG. 156

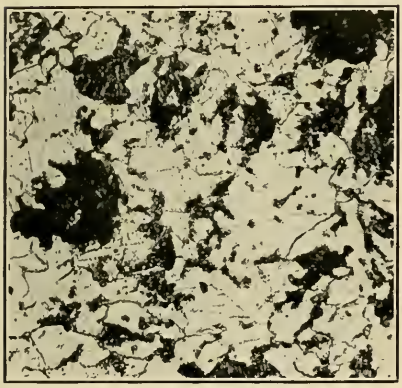


FIG. 157

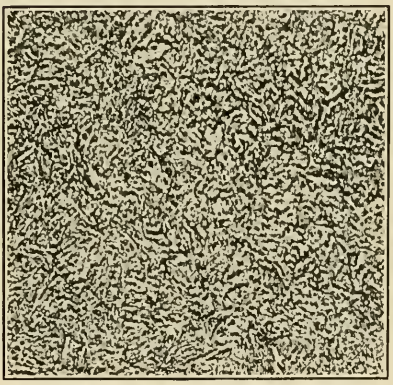


FIG. 158

FIG. 155. Nickel-chromium steel. Annealed. 0.30% carbon; 1.75% nickel; 1.00% chromium. S. A. E. Steel No. 3230 annealed. Etched in 5% Nital. 500×.

FIG. 156. Nickel-chromium steel. Heat treated. 0.30% carbon; 1.75% nickel; 1.00% chromium. Normalized at 913° C. Heated to 829° C., quenched in oil. Tempered at 191° C. S. A. E. Steel No. 3230 after recommended heat treatment VII. Etched in 5% Nital. 500×.

FIG. 157. Nickel-chromium steel. Annealed. 0.35% carbon; 3.50% nickel; 1.50% chromium. S. A. E. Steel No. 3335 annealed. Etched in 5% Nital. 500×.

FIG. 158. Nickel-chromium steel. Heat treated. 0.35% carbon; 3.50% nickel; 1.50% chromium. Normalized at 899° C. Heated to 746° C., cooled slowly in furnace, reheated to 743° C., quenched in oil. Drawn at 538° C. S. A. E. Steel No. 3335 after recommended heat treatment VIII. Etched in 5% Nital. 500×.

D. CHROMIUM-VANADIUM STEEL

Annealed and after recommended heat treatment

Figs. 159-162 inclusive

ALLOY STEEL — CHROME-VANADIUM STEEL

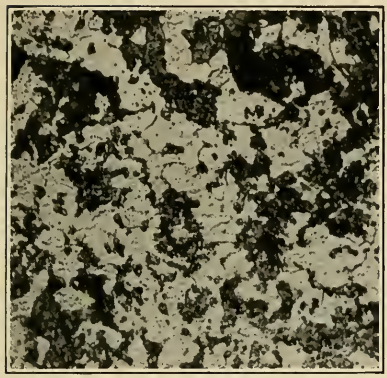


FIG. 159

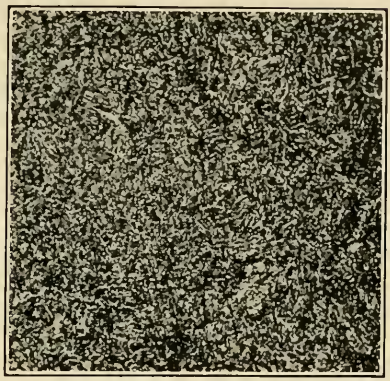


FIG. 160

FIG. 161

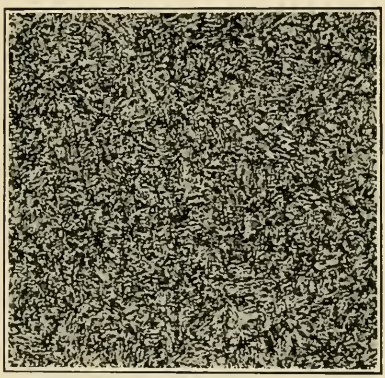


FIG. 162

FIG. 159. Chrome-vanadium steel. Annealed. 0.35% carbon; 0.95% chromium; 0.18% vanadium. S. A. E. Steel No. 6135 annealed. Etched in 5% Nital. 500×.

FIG. 160. Chrome-vanadium steel. Heat treated. 0.35% carbon; 0.95% chromium; 0.18% vanadium. Normalized at 913° C., reheated to 704° C., cooled slowly. Reheated to 871° C., quenched in oil. Drawn at 538° C. S. A. E. Steel No. 6135 after recommended heat treatment VIII. Etched in 5% Nital. 500×.

FIG. 161. Chrome-vanadium steel. Annealed. 1.00% carbon; 0.90% chromium; 0.18% vanadium. S. A. E. Steel No. 6195 annealed. Etched in 5% Nital. 500×.

FIG. 162. Chrome-vanadium steel. Heat treated. 1.00% carbon; 0.90% chromium; 0.18% vanadium. Heated to 829° C., quenched in oil. Drawn at 538° C. S. A. E. Steel No. 6195 after recommended heat treatment VI. Etched in 5% Nital. 500×.

E. MOLYBDENUM STEEL

Annealed and after recommended heat treatment

Figs. 163 and 164

ALLOY STEEL — MOLYBDENUM STEEL

FIG. 163

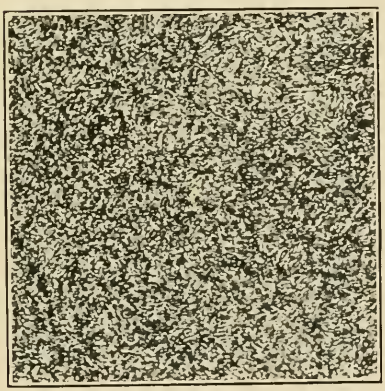


FIG. 164

FIG. 163. Molybdenum steel. Annealed. 0.40% carbon; 0.95% chromium; 0.20% molybdenum. S. A. E. Steel No. 4140 annealed. Etched in 5% Nital. 500×.

FIG. 164. Molybdenum steel. Heat treated. 0.40% carbon; 0.95% chromium; 0.20% molybdenum. Normalized at 927° C., reheated to 704° C., cooled slowly, reheated to 857° C., quenched in oil. Drawn at 538° C. S. A. E. Steel No. 4140 after recommended heat treatment VIII. Etched in 5% Nital. 500×.

F. HADFIELD MANGANESE STEEL

Cast and after recommended heat treatment

Figs. 165-167 inclusive

ALLOY STEEL — MANGANESE STEEL

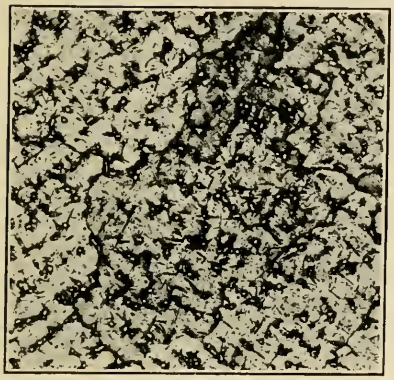


FIG. 165

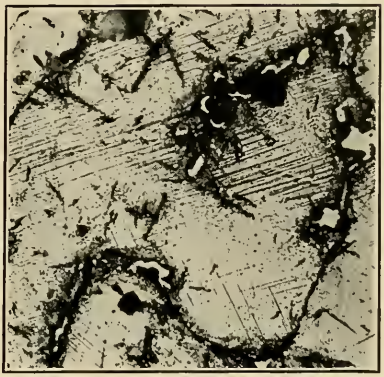


FIG. 166

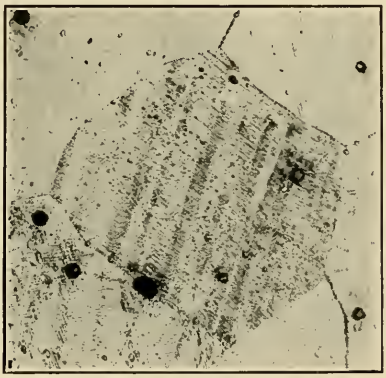


FIG. 167

FIG. 165. Manganese steel. Cast. 1.00% carbon; 12.00% manganese. Free carbides in matrix of austenite. Etched in 5% Nital. 50×. Original magnification, 100×.

FIG. 166. Manganese steel. Cast. Same as in Fig. 165, more highly magnified. Carbides of manganese in austenite matrix. Deformation lines in austenite.

FIG. 167. Manganese steel. Cast. Heat treated. 1.00% carbon; 12% manganese. Heated to 1100° C. and quenched in cold water. Grains of austenite. Deformation lines in austenite grain. Etched in 5% Nital. 250×. Original magnification, 500×.

SILICON STEEL

(AS CAST)

Fig. 168

ALLOY STEEL — SILICON STEEL

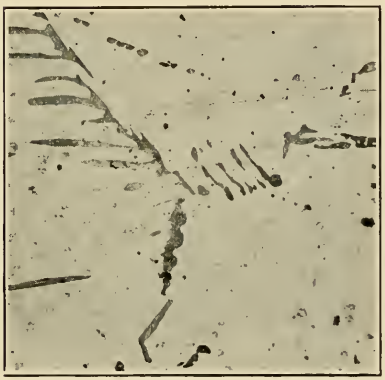


FIG. 168

FIG. 168. Silicon steel. Cast. 0.15% carbon; 4.50% silicon. Typical large grain size of high silicon steel. Etched in 5% Nital. 50×. Original magnification, 100×.

SILICO-MANGANESE STEEL

Annealed and after recommended heat treatment

Figs. 169 and 170

ALLOY STEEL — SILICO-MANGANESE STEEL

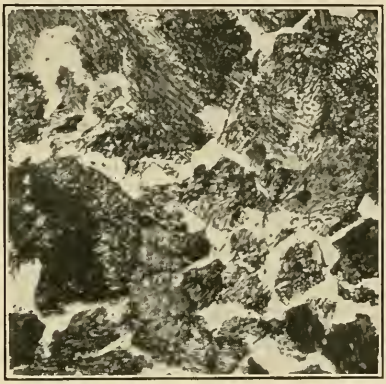


FIG. 169

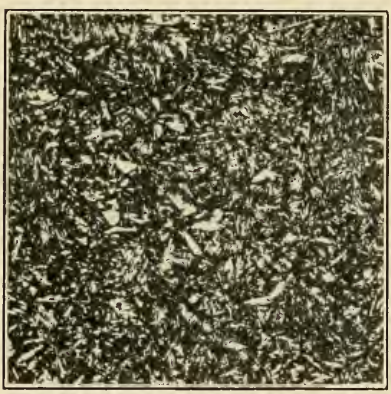


FIG. 170

FIG. 169. Silico-manganese steel. Annealed. 0.50% carbon; 0.75% manganese; 2.00% silicon. S. A. E. Steel No. 9260 annealed. Etched in 5% Nital. 500×.

FIG. 170. Silico-manganese steel. Heat treated. 0.50% carbon; 0.75% manganese; 2.00% silicon. Normalized at 927° C., reheated to 763° C., cooled slowly, reheated to 885° C., quenched in oil. Drawn at 538° C. S. A. E. Steel No. 9260 after recommended heat treatment VIII. Etched in 5% Nital. 500×.

CHROME-TUNGSTEN STEEL

(HIGH-SPEED STEEL)

Cast, annealed, and after recommended heat treatment

Figs. 171–177 inclusive

ALLOY STEEL — CHROME-TUNGSTEN STEEL

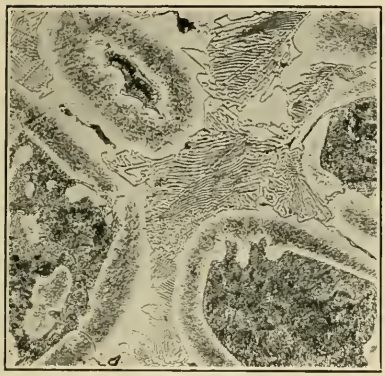


FIG. 171

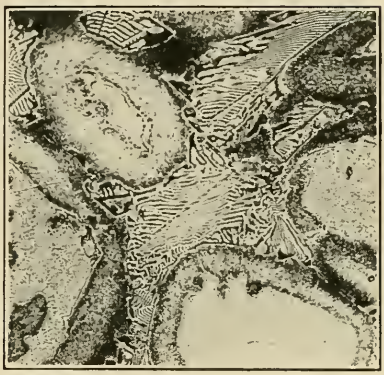


FIG. 172

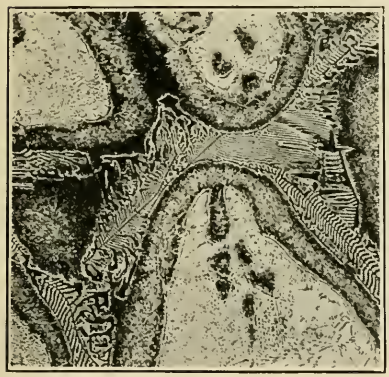


FIG. 173

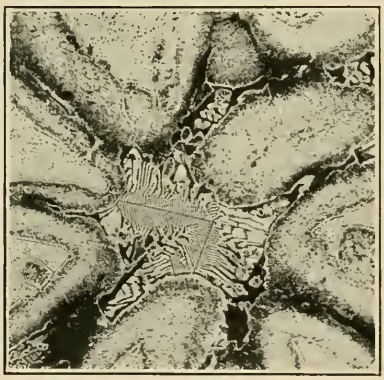


FIG. 174

FIG. 171. High-speed steel. Cast. 0.60% carbon; 17.00% tungsten; 3.50% chromium. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 172. Same spot as in Fig. 171. After repolishing and etching in Murakami's reagent. 250×. Original magnification, 500×.

FIG. 173. Another spot on specimen shown in Fig. 172. After etching in Murakami's reagent. 250×. Original magnification, 500×.

FIG. 174. Another spot on specimen shown in Fig. 172. After etching in Murakami's reagent. 250×. Original magnification, 500×.

ALLOY STEEL — CHROME-TUNGSTEN STEEL

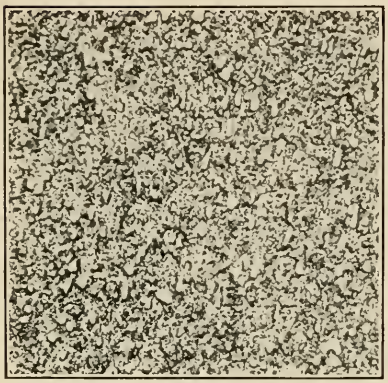


FIG. 175

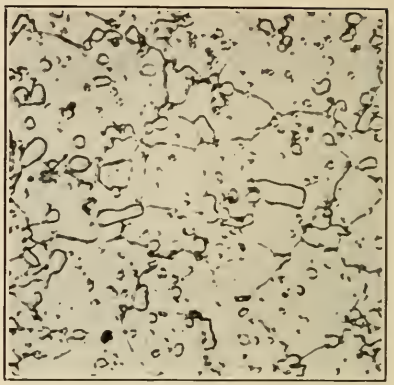


FIG. 176

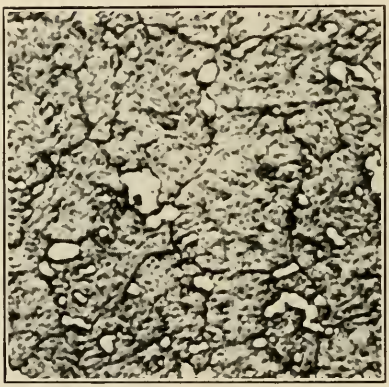


FIG. 177

FIG. 175. High-speed steel. Annealed. 0.60% carbon; 17.00% tungsten; 3.50% chromium. Carbides of chromium and tungsten in a sorbitic matrix. Etched in 5% Nital. 500×.

FIG. 176. High-speed steel. Heat treated. 0.60% carbon; 17.00% tungsten; 3.50% chromium. Preheated in a salt bath to 926° C., then heated in a second salt bath to 1204° C., and quenched in a third salt bath at 593° C. Carbides of tungsten and chromium in austenitic matrix. Etched in 1% Nital and subsequently in Kourbatoff's reagent. 1000×.

FIG. 177. High-speed steel. Heat treated. 0.60% carbon; 17.00% tungsten; 3.50% chromium. Preheated to 816° C., heated to 1288° C., quenched in oil, and drawn at 593° C. Etched in 1% Nital and subsequently in Kourbatoff's reagent. 1000×.

J. SPECIAL ALLOY STEEL CONTAINING TUNGSTEN AND CHROMIUM

Possessing properties of hardness after recommended heat treatment. — Seminole Steel.

Figs. 178-180 inclusive

ALLOY STEEL — CHROME-TUNGSTEN STEEL

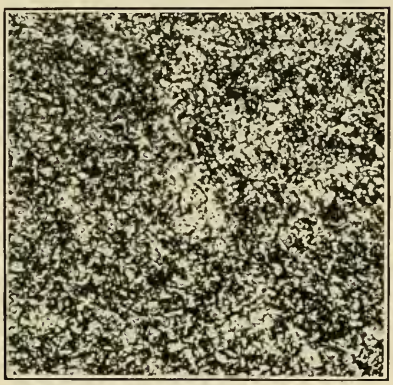


FIG. 178

FIG. 178. Seminole steel as received. Containing tungsten and chromium. Etched in 5% Nital. 500×.

ALLOY STEEL — CHROME-TUNGSTEN STEEL

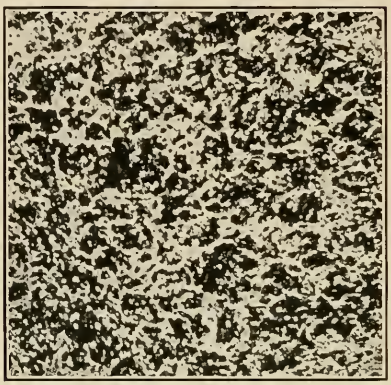


FIG. 179

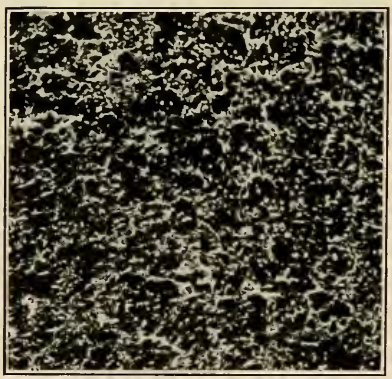


FIG. 180

FIG. 179. Seminole steel. Hardened. Containing tungsten and chromium. Etched in 5% Nital. 500×.

FIG. 180. Seminole steel. Hardened and tempered. Containing tungsten and chromium. Etched in 5% Nital. 500×. This steel possesses properties of hardness and toughness.

K. NON-SCALING STEEL

Hadfield Era A.T.V. Alloy Steel

Fig. 181

ALLOY STEEL — HADFIELD ERA — A.T.V. NON-SCALING STEEL

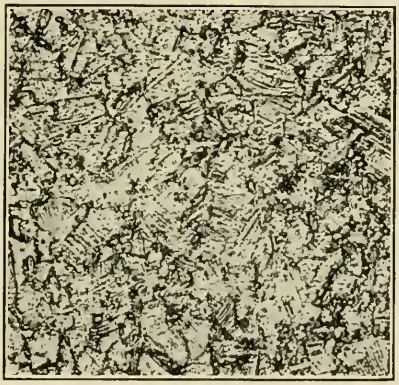


FIG. 181

FIG. 181. Hadfield Era — A.T.V. Non-scaling steel after heating to 926° C. and cooling in air. Etched in 5% Nital. 500×.

CASE-HARDENED ALLOY STEEL AFTER RECOMMENDED HEAT TREATMENT

1. Nickel steel, Fig. 182
2. Chromium steel, Fig. 183
3. Nickel-chromium steel, Fig. 184
4. Molybdenum steel, Fig. 185
5. Chrome-vanadium steel, Fig. 186

CASE-HARDENED ALLOY STEEL

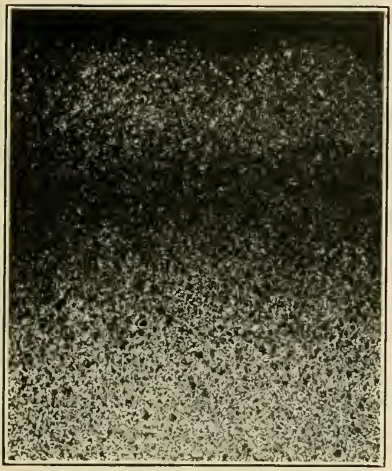


FIG. 182

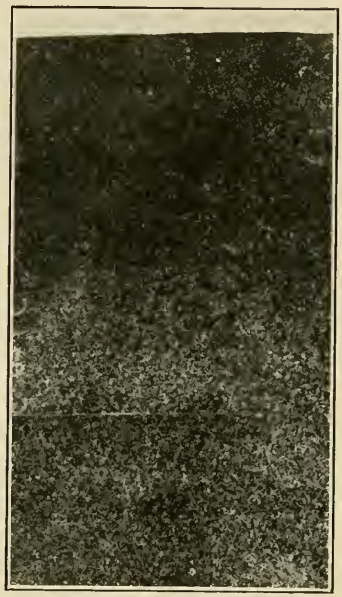


FIG. 183

FIG. 182. Nickel steel. Case-hardened and heat treated. 0.20% carbon; 5.00% nickel. Cooled slowly in box after case-hardening and subsequently subjected to double heat treatment. 50×. Original magnification, 100×.

FIG. 183. Chromium steel. Case-hardened and heat treated. 0.20% carbon; 0.75% chromium. Carburized at 913° C., cooled in box. Reheated to 885° C., quenched in oil; reheated to 743° C., quenched in oil. S. A. E. Steel No. 5120 after recommended heat treatment V. Drawn at 191° C. Etched in 5% Nital. 50×. Original magnification, 100×.

CASE-HARDENED ALLOY STEEL

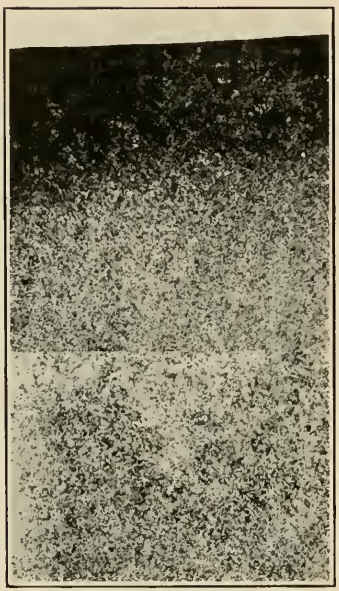


FIG. 184

FIG. 185

FIG. 184. Nickel-chromium steel. Case-hardened and heat treated. 0.17% carbon; 3.50% nickel; 1.50% chromium. Carburized 7 hours at 885° C., cooled in box. Reheated to 843° C., quenched in oil; reheated to 759° C., quenched in oil. Tempered at 191° C. S. A. E. Steel No. 3312 after recommended heat treatment V. Etched in 5% Nital. 50×. Original magnification, 100×.

FIG. 185. Molybdenum steel. Case-hardened and heat treated. 0.15% carbon; 1.50% nickel; 0.25% molybdenum. Carburized at 885° C., cooled in box. Reheated to 843° C., quenched in oil; reheated to 759° C., quenched in oil. Tempered at 191° C. S. A. E. Steel No. 4615 after recommended heat treatment V. Etched in 5% Nital. 50×. Original magnification, 100×.

CASE-HARDENED ALLOY STEEL

Fig. 186

Fig. 186. Chrome-vanadium steel. Case-hardened and heat treated. 0.20% carbon; 0.95% chromium; 0.18% vanadium. Carburized at 913° C., cooled in box. Reheated to 885° C., quenched in oil; reheated to 742° C., quenched in oil. Tempered at 191° C. S. A. E. Steel No. 6120 after recommended heat treatment V. Etched in 5% Nital. 50×. Original magnification, 100×.

ANNEALED NITRALLOY

(STEEL USED FOR NITRIDING)

AND

NITRIDED STEELS

Figs. 187-193 inclusive

NITRALLOY AND NITRIDED NITRALLOY

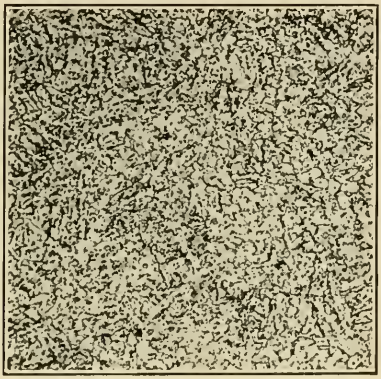


FIG. 187

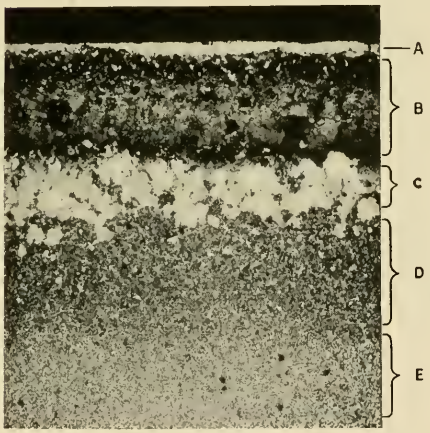


FIG. 188

FIG. 187. Nitralloy. Annealed. 0.36% carbon; 0.51% manganese; 0.27% silicon; 1.23% aluminum; 1.49% chromium; 0.010% sulphur; 0.013% phosphorus; 0.18% molybdenum. Etched in 5% Nital. 500×.

FIG. 188. Nitralloy after subjected to nitriding process. Etched in 5% Nital. 50×. Original magnification, 100×.

NITRIDED NITRALLOY

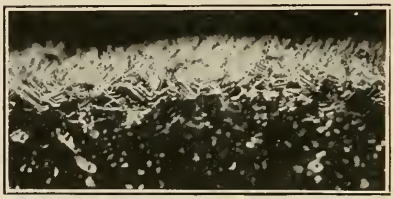


FIG. 189

FIG. 190

FIG. 191

FIG. 189. Microstructure of section *A*. Shown in Fig. 188. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 190. Microstructure of section *B*. Shown in Fig. 188. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 191. Microstructure of section *C*. Shown in Fig. 188. Etched in 5% Nital. 250×. Original magnification, 500×.

NITRIDED NITRALLOY

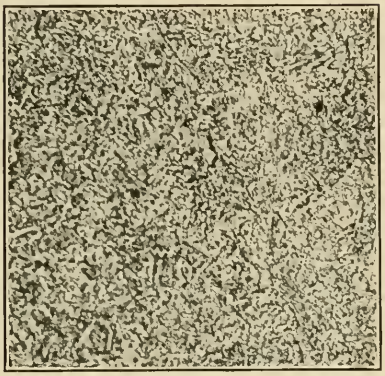


FIG. 192

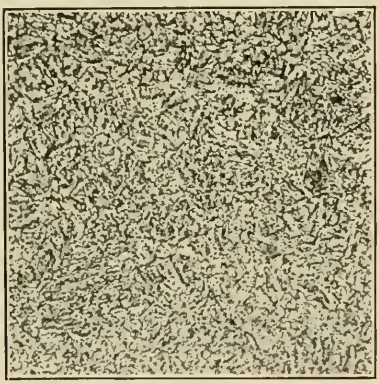


FIG. 193

FIG. 192. Microstructure of section *D*. Shown in Fig. 188. Etched in 5% Nital. 500×.

FIG. 193. Microstructure of section *E*. Shown in Fig. 188. Metal unaffected by nitriding. Etched in 5% Nital. 500×.

CAST IRON

(GRAY IRON)

Figs. 194-201 inclusive

GRAY CAST IRON

FIG. 194

FIG. 195

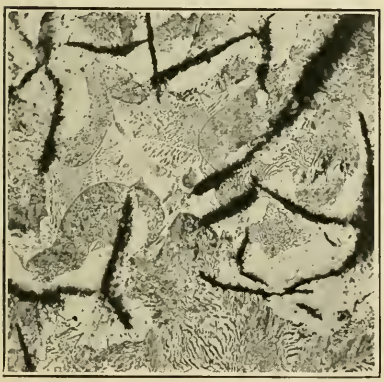


FIG. 196

FIG. 197

FIG. 194. Gray cast iron. No combined carbon. Graphite and ferrite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 195. Gray cast iron. No combined carbon. Graphite, ferrite and steadite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 196. Gray cast iron. Hypo-eutectoid matrix, containing about 0.40% combined carbon. Graphite, pearlite, ferrite and steadite.

FIG. 197. Gray cast iron. Hypo-eutectoid matrix, containing about 0.60% combined carbon. Graphite, pearlite and ferrite. 250×. Original magnification, 500×.

GRAY CAST IRON

FIG. 198

FIG. 199

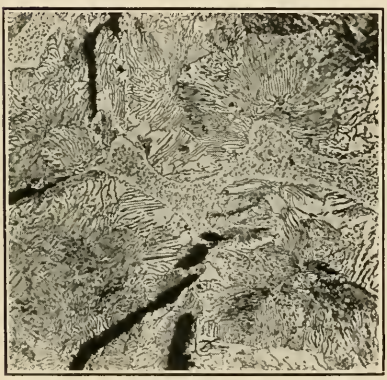


FIG. 200

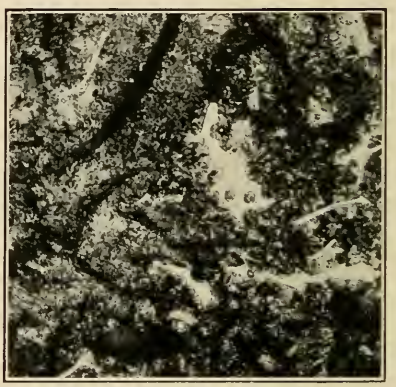


FIG. 201

FIG. 198. Gray cast iron. Hypo-eutectoid matrix, containing about 0.60% combined carbon. Graphite, pearlite, steadite and ferrite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 199. Gray cast iron. Eutectoid matrix, containing about 0.85% combined carbon. Graphite and pearlite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 200. Gray cast iron. Eutectoid matrix, containing about 0.85% combined carbon. Graphite, pearlite and steadite. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 201. Gray cast iron. Hyper-eutectoid matrix, containing about 1.25% combined carbon. Graphite, sorbite and cementite. Etched in 5% Nital. 250×. Original magnification, 500×.

MOTTLED CAST IRON

Fig. 202

MOTTLED CAST IRON

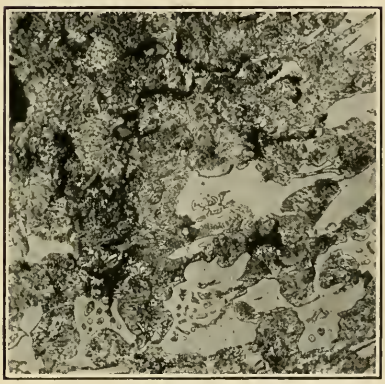


FIG. 202

FIG. 202. Mottled cast iron. Cementite, pearlite and graphite. Etched in 5% Nital. 250×. Original magnification, 500×.

WHITE CAST IRON

Figs. 203 and 204

WHITE CAST IRON

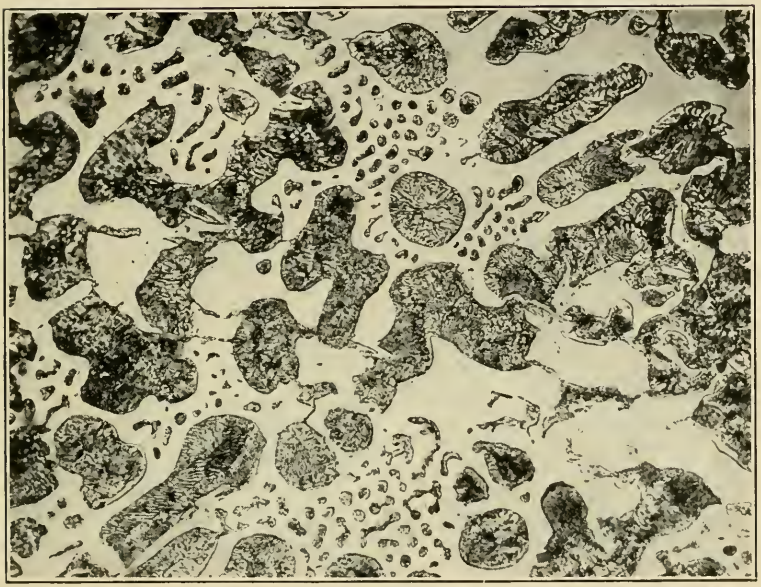


FIG. 203

FIG. 203. White cast iron. Cementite and pearlite. Etched in 5% Nital. 375×. Original magnification, 500×.

WHITE CAST IRON

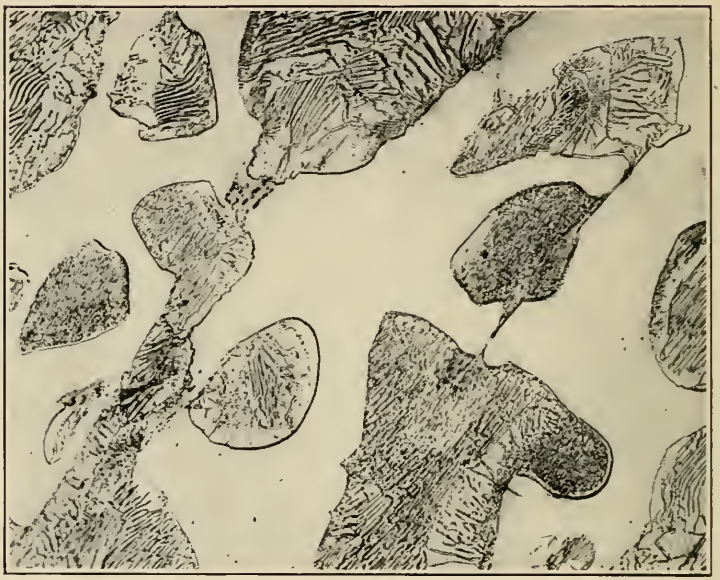


FIG. 204

FIG. 204. White cast iron. Cementite and pearlite. Etched in 5% Nital. 375×. Original magnification, 500×.

MALLEABLIZED CAST IRON

Figs. 205 and 206

PARTIALLY MALLEABLIZED CAST IRON

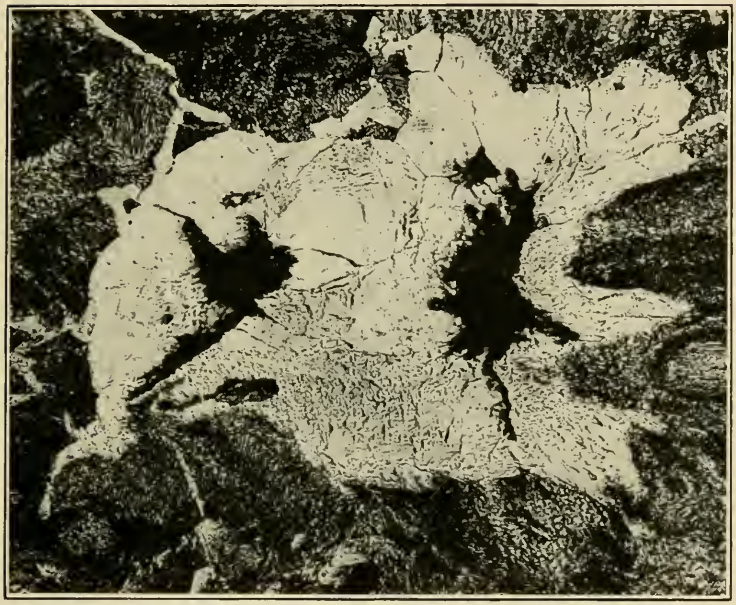


FIG. 205

FIG. 205. Cast iron. Partially malleablized. Ferrite, temper-carbon and sorbito-pearlite. Etched in 5% Nital. 375×. Original magnification, 500×.

FULLY MALLEABLIZED CAST IRON

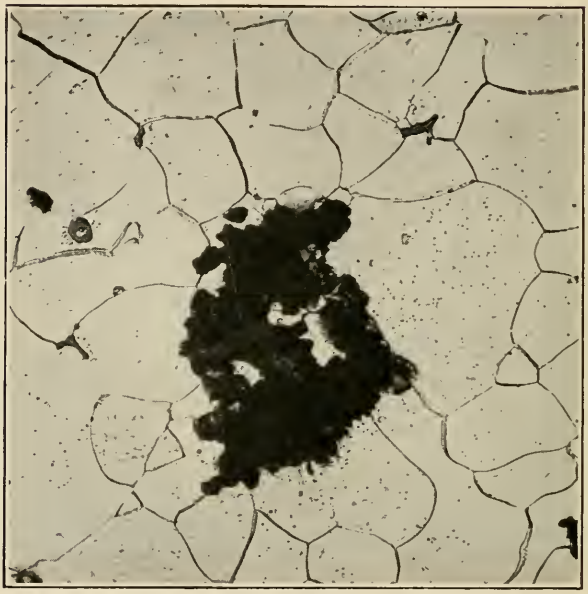


FIG. 206

FIG. 206. Cast iron. Fully malleablized. Ferrite and temper-carbon. Etched in 5% Nital. 375×. Original magnification, 500×.

MANGANESE SULPHIDE IN CAST IRON

Fig. 207

MANGANESE SULPHIDE IN MALLEABLIZED CAST IRON

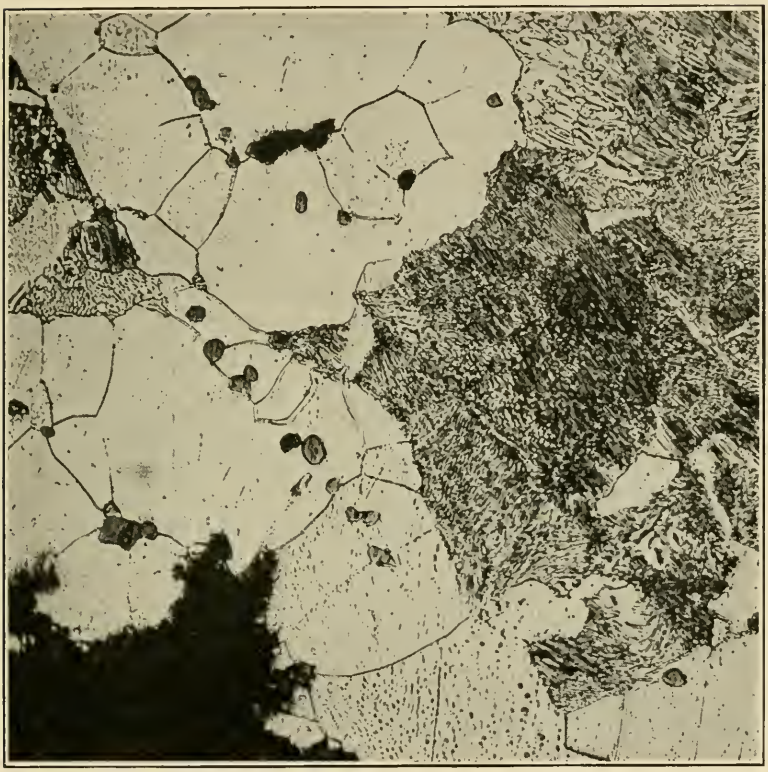


FIG. 207

FIG. 207. Manganese Sulphide in partially malleablized cast iron. Rounded particles of dove-gray manganese sulphide in ferrite. Temper-carbon and sorbito-pearlite present. Etched in 5% Nital. 500×.

PHOSPHIDE EUTECTIC IN CAST IRON

Figs. 208-210 inclusive

PHOSPHIDE EUTECTIC

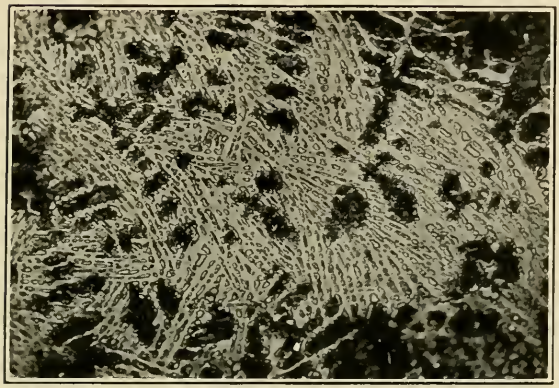


FIG. 208

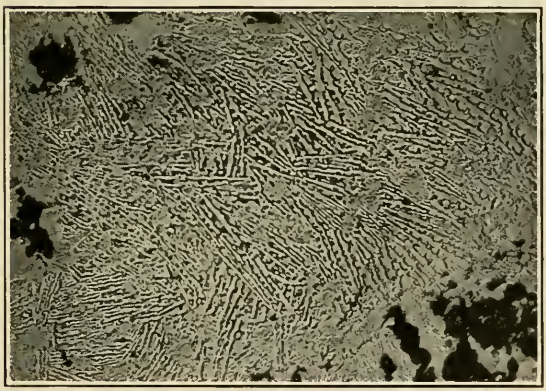


FIG. 209

FIG. 208. Phosphide eutectic after etching in 5% Nital. 250×. Original magnification, 500×.

FIG. 209. Same as in Fig. 208, after repolishing and etching in sodium picrate. 250×. Original magnification, 500×.

PHOSPHIDE EUTECTIC

FIG. 210

FIG. 210. Same spot as shown in Fig. 209, after repolishing and heat-tinting.* The dark-colored plates in the print represent a deep lavender color, — phosphorus rich areas. The bright-colored plates in the eutectic represent a yellowish-red color — cementite areas. 250×. Original magnification, 500×.

* The polished specimen was placed on a hot plate and heated by a Bunsen gas burner until the phosphorus rich areas were tinted a deep lavender.

CHILLED CAST IRON

Showing a series of Photomicrographs of a chilled casting

Figs. 211-213 inclusive

CHILLED CAST IRON

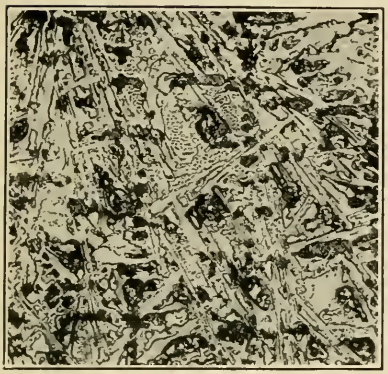


FIG. 211

FIG. 212

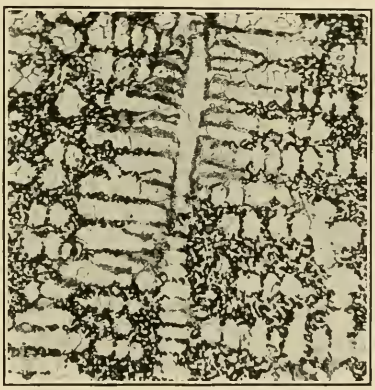


FIG. 213

FIG. 211. Microstructure of chilled face of gray iron casting. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 212. Microstructure of junction of chill and gray iron. Etched in 5% Nital. 250×. Original magnification, 500×.

FIG. 213. Microstructure of gray iron. Etched in 5% Nital. 250×. Original magnification, 500×.

SEMI-STEEL

Comparative microstructures of gray cast iron with a eutectoid matrix, Fig. 214, and a semi-steel with a eutectoid matrix, Fig. 215

SEMI-STEEL

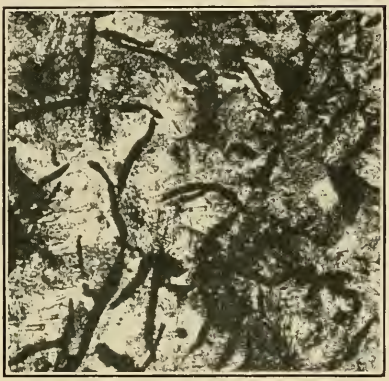


FIG. 214

FIG. 215

FIG. 214. Gray cast iron. Eutectoid matrix. Large graphite plates, sorbito-pearlite, and steadite. Etched in 5% Nital. 100×.

FIG. 215. Semi-steel. Eutectoid matrix. Small graphite plates, sorbito-pearlite and traces of steadite. Etched in 5% Nital. 100×.

CAST IRON CONTAINING SPECIAL ELEMENTS

Figs. 216-218 inclusive

SPECIAL ELEMENTS IN GRAY CAST IRON

FIG. 216

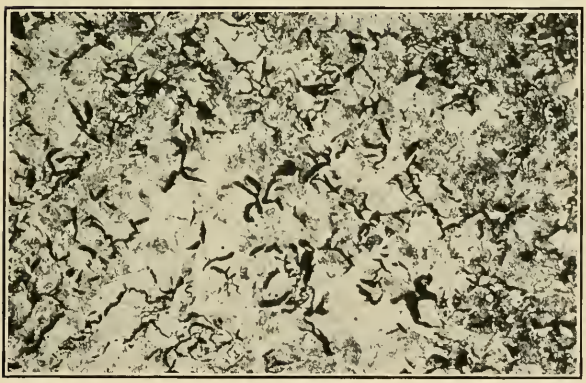


FIG. 217

FIG. 216. Gray cast iron. Hypo-eutectoid matrix. 3.16% total carbon; 2.63% silicon. Etched in 5% Nital. 100×.

FIG. 217. Nickel. Gray cast iron. Hypo-eutectoid matrix. 3.17% total carbon; 1.14% silicon; 2.83% nickel. Etched in 5% Nital. 100×.

SPECIAL ELEMENTS IN GRAY CAST IRON

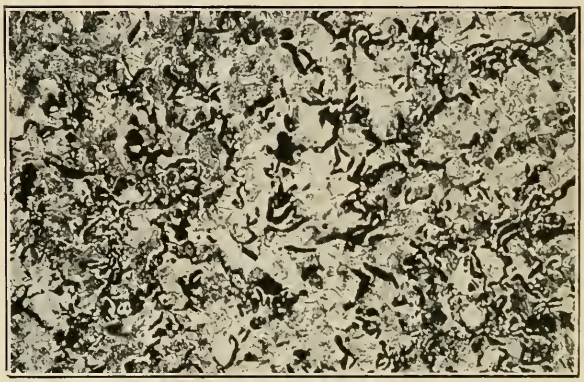


FIG. 218

FIG. 218. Nickel-Chromium. Gray cast iron. Hypo-eutectoid matrix. 3.11% total carbon; 2.20% silicon; 1.11% nickel, and 0.38% chromium. Etched in 5% Nital. 100×.

APPENDICES

APPENDIX A

THE PREPARATION OF METALLOGRAPHIC SPECIMENS*

By H. M. Boylston, Professor of Metallurgy, Case School of Applied Science, Cleveland, Ohio.

Selection of Specimen. — Metallographic specimens should be so selected as to be representative of the metal from which they are taken. Where the piece has failed in service it is important that a specimen should be taken from near the failure and one considerably distant from it for comparison or samples may sometimes be obtained from similar pieces which have stood up well in service.

When samples are taken from near a fracture, the metal very close to the fracture itself should be examined. The fracture edge should not be bevelled and sometimes it is well to electroplate the fractured surface with copper (Rosenhain), in order to protect the fracture from bevelling during subsequent grinding and polishing operations. Embedding the plated specimen in fusible metal, as explained below, is sometimes advisable.

Note should be made of the location of the specimen in the piece and the relation of the surface to be polished to the direction of forging and rolling. A sketch is very helpful in this connection.

Removal of Specimen. — Specimens are generally cut off with a hack saw. Tough steels, like manganese steel and other austenitic material, hardened steels, or even white cast iron, which cannot be cut with a hack saw, may be cut easily with a thin alundum or carborundum disc, three-thirty-seconds of an inch thick and running in water, if it is necessary to prevent tempering. If no cutting disc is available brittle specimens may be broken with a hammer, although this means a rough surface to grind down later.

Dimensions of Specimen. — Much time is saved by keeping the specimen small within reasonable limits. A one-half inch square or round piece is a good size unless the microscope is of such construction that a larger piece is necessary in order to prevent it from slipping through the stage. It is much easier and quicker to polish four pieces each one-half inch square than it is to polish one piece one inch square. The thickness of the specimen should be less than the other dimensions, if possible, since the thicker the specimen the more difficult it is to hold it on the grinding and polishing wheels without rounding the surface. A one-half inch square or round piece should be preferably not over three-eighths inch thick. Very small specimens may be embedded

* Printed from the American Society for Steel Treating handbook, by permission.

in some fusible metal, sealing wax, fiber or by mounting in suitable metal clamps. (See Figs. 1, 2, and 3.) By these means the finest wire, turnings and even filings may be polished and examined. The following alloy, suggested by Champion and Ferguson, which melts in boiling water, is very useful in mounting small specimens:

Bismuth	50 parts by weight
Lead	30 parts by weight
Tin	25 parts by weight
Zinc	3 parts by weight

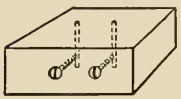


Fig. 1

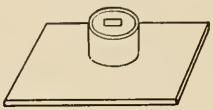


Fig. 2

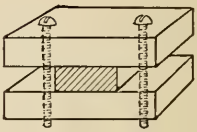


Fig. 3

Figs. 1 and 3. — Polishing Clamps for Specimens. Fig. 2. — Container for Mounting Specimens in Balsam or Low Melting Alloys.

The inexpensive small iron cups known in the trade as "malleable gas caps," either three-eighths or one-quarter inch size, are very useful for holding the alloy and the specimen. The cap is heated to about 392 degrees Fahr. by placing it on an electric stove or on an iron plate heated by a bunsen burner. The fusible alloy is then placed in it and melted. The temperature is then reduced until the cap and metal are just a little above 212 degrees Fahr. and the specimen to be polished is then pressed into the metal. The cap and its contents may then be solidified and cooled, and polished like any other specimen. If the nature of the specimen will allow it, it should be dipped into a saturated solution of zinc chloride before placing in the alloy. The zinc chloride acts as a flux and cleans the surface of the specimen so that a better joint is made between it and the mounting metal. It is obvious that any metal that alloys with the mounting metal cannot be mounted in this way.

Grinding and Polishing. — It was at one time thought necessary to grind and polish by hand, but this is a tedious and slow method. Power grinding and polishing have now been in successful use for many years and are recommended except where very soft metals or alloys are to be prepared, when special precautions have to be observed. Grinding and polishing are generally carried out in three or more steps:

a. Grinding or filing to obtain a flat surface.
b. Rough polishing.
c. Fine polishing generally including two or more steps.

Grinding. — A medium fine and medium hard grinding wheel is generally used for this purpose. Grade 80-P alundum wheel or No. 2 French emery

paper gives good results. Some grind on a coarse file, but this is preferably restricted to soft metals. Grinding wheels may be mounted either vertically or horizontally and should be run at a speed of about 1200 R.P.M. The specimen should be kept cool on the grinding wheel by having water drip on it. Light pressure should be maintained on the specimen on all wheels or papers, whether for grinding or polishing. The edges of the specimen should be bevelled where possible, in order to protect the cloth or paper from being cut. Specimens should be washed thoroughly in water after the grinding operation, in order to remove any trace of abrasives. There are two reasons for grinding specimens: first, to remove the marks of the saw or cutting disc, and in order to know when this has been accomplished it is wise to hold the specimen so that the grinding marks are at right angles to those already found on the surface to be prepared. The second reason for grinding is to have an absolutely flat surface.

Rough Polishing. — This may be done with grade FF Turkish flour emery powder or French emery paper No. 1. The powder should be suspended in water and used on a smooth wheel of some sort covered with 12 ounce canvas duck. Very little powder and much water should be used, and again the specimen should be turned 90 degrees so that the scratches produced by the powders or papers will be at right angles to those produced in grinding. The specimen should be washed thoroughly in water before passing to the next step, to remove all traces of abrasives. Some prefer to supplement the rough polish with French emery paper 0, 00 and 000.

Fine Polishing. — Two or more steps are generally used. In the first step white reground tripoli powder or alundum powder No. 600 may be used in water suspension and placed on a wheel covered with a fine grade of broadcloth. The cloth should not be too thick or a relief polish will be obtained. Plenty of water and not too much powder should be used.

The last operation may be performed with fine levigated alumina, grade No. 3, or with "superfine" magnesia powder. The best soft, high grade, jewelers' rouge powder may also be used. Levigated alumina or magnesia generally give better results than rouge, which is apt to scratch soft specimens. For this final operation "kitten's ear" silk broadcloth is preferable. When levigated alumina is used it should be suspended in water and squirted on the cloth disc by means of a devilbiss atomizer or any other type having a broad orifice. If magnesia is used it will harden and cake slightly unless the cloth is removed each time and kept soaked in a weak solution (2 per cent) of hydrochloric acid (HCl) in distilled water. An exceptionally small amount of powder is necessary in the final polishing operation.

Except where otherwise indicated, all suspended powders may be placed on the cloth covered disc by means of rubber set varnish brushes. Some prefer to wash off the powder from the cloth in the final polishing and polish for a few moments on the cloth alone, which is thoroughly wet with water.

While the speed for grinding has been given as 1200 R.P.M. it is better to use lower speeds in the three other operations; namely, 300 to 600 R.P.M.

In every case specimens should be washed thoroughly after each stage of the operation.

Especially soft metals, like lead alloys, must be ground and polished by hand throughout the entire operation. In grinding the soft specimens the specimens should be rubbed over the file and not have the file passed over them.

Washing and Drying. — Specimens should be thoroughly washed in water after polishing and then washed in two baths of absolute alcohol and dried immediately by means of a blower. The best instrument for drying is some form of barbers' hair dryer. Specimens should not be touched with the fingers after washing and drying or a greasy surface will be produced which will not etch evenly. Specimens should be carefully wrapped in cotton or placed in a desiccator until ready to etch and in the case of copper alloys etching and photography should be carried out as promptly as possible to avoid troubles due to tarnish.

References

Sauveur's Metallography and Heat Treatment of Iron and Steel, third edition, 1926.

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APPENDIX B

ETCHING SOLUTIONS FOR MICROSCOPIC EXAMINATIONS OF STEELS AND IRONS*

Etching Reagents†	Composition	Remarks	Uses
1a. Nitric acid (5 per cent Nital)	5 cc. nitric acid, conc., and 95 cc. of either methyl or ethyl alcohol (absolute).	Only clear white nitric acid, 1.42 sp. gr., should be used. In order to avoid tarnish troubles, specimens, after etching in either Nital or Picral, should be washed in at least two baths of methyl or ethyl alcohol (absolute) to remove the traces of acid. Specimens should then be dried quickly, preferably with a clean air blast (cold or warm). Proposed by Boylston.	These reagents are recommended for etching to show Pearlite (both lamellar and granular), sorbite, ferrite and grain boundaries in steels and irons (including cast iron). Nital brings out ferrite junction lines clearly while both Nital and Picral etch pearlite clearly. Carbides are unetched by these reagents.
1b. (1 per cent Nital)	1 cc. conc. nitric acid and 99 cc. of methyl or ethyl alcohol (absolute).	Proposed by Boylston.	For hardened or heat treated carbon steels.

* Prepared by the Sub-Committee of the Recommended Practice Committee of the A. S. S. T. on Etching Solutions for Iron and Steel. Printed from the American Society for Steel Treating handbook, by permission.

† These solutions are recommended for general use for etching annealed and hardened plain carbon and alloy steels, as indicated under the heading "Uses."

Etching Reagents†	Composition	Remarks	Uses
2. Picric acid (5 per cent Picral)	Saturated solution (about 5 grms.) picric acid in 100 cc. of methyl or ethyl alcohol (absolute).	Sometimes better results are obtained by etching for a short time first in 5 per cent Nital and then in 5 per cent Picral.	
3. Hydrochloric acid	1 cc. conc. hydrochloric acid and 100 cc. water.	Proposed by Martens and Heyn.	For hardened steels. May dilute with 500 cc. of distilled water and use weak electric current.
4. Sodium picrate	2 grms. picric acid; 25 grms. sodium hydroxide; water to make 100 cc.	Use boiling 5 to 10 minutes. Cementite colored. In tungsten steels, iron-tungstide (Fe_nW) and iron-tungsten carbide (Fe_2W_2C) are colored, but tungsten carbide is unaffected. This reagent is most easily prepared by dissolving 25 grms. of NaOH in 60 to 70 cc. of water; add 2 grms. of picric acid and heat until dissolved; make up to 100 cc. with water. Keep at this volume. The mixture should always be alkaline as tested with litmus paper. Proposed by LeChatelier.	Cementite and other carbides.

Etching Reagents†	Composition	Remarks	Uses
5. Hydrogen peroxide and sodium hydroxide	10 cc. hydrogen peroxide; 20 cc. 10 per cent sodium hydroxide in water.	Use fresh. Etch 10 to 12 minutes. Tungsten carbide is darkened. Proposed by Yatsevitch.	Attacks and darkens iron-tungstide in carbon free iron-tungsten alloys. When carbon is present this solution darkens the compound (FeW + WC?) in proportion to the amount of carbon present.
6. Ferricyanide	10 grms. potassium ferricyanide; 10 grms. potassium hydroxide; 100 cc. water.	May be used cold or hot, but should be freshly made. Proposed by Murakami.	Carbides and tungstides in tungsten and high speed steels. Structure of Stellite.
7a. Ferric chloride and hydrochloric acid	10 grms. ferric chloride; 30 cc. hydrochloric acid; 120 cc. water.	Apply with a piece of cotton, rub gently, then wash with water and finally with alcohol. The time is lengthened by using a more dilute solution, allowing closer control of the depth of etching. The time is rarely over 30 seconds. May be used electrolytically with very dilute solutions. Proposed by Curran.	Structure of stainless steel.
7b.	5 grms. ferric chloride; 50 cc. hydrochloric acid; 100 cc. water.		Structure of austenitic nickel steels.

Etching Reagents†	Composition	Remarks	Uses
8. Aqua Regia	3 parts hydrochloric acid, conc.; 1 part nitric acid, conc.	The mixture should stand 24 hours before using. It is used full strength for rapid work, but requires very careful handling.	Structure of stainless steel.
9. Cupric chloride (Stead's reagent)	10 grms. cupric chloride; 40 grms. magnesium chloride; 20 cc. hydrochloric acid, conc.; hot water, and alcohol to make 1000 cc.	Dissolve the salts in the least possible quantity of hot water and make up to 1000 cc. with alcohol. Cover specimen with a thin layer of the reagent and allow it to stand for 1 minute. Shake off the reagent and add a fresh layer, allow it to stand for 1 minute more. Repeat as often as it is found desirable. Wash with boiling water and alcohol. Indicates presence of phosphorus segregations and by progressive etching the difference between the phosphorus in different portions of the same metal is shown. Proposed by Stead.	

ADDITIONAL ETCHING SOLUTIONS FOR SPECIAL PURPOSES FOR ALLOY STEELS*

Reagent	Composition	Remarks	Used to Show
1. Copper sulphate	4 grms. copper sulphate; 20 cc. hydrochloric acid; 20 cc. water.	Proposed by Marble.	Structure of stainless steel.
2. Ferric chloride and nitric acid	Saturated solution of ferric chloride in hydrochloric acid, to which a little nitric acid is added.	Used full strength.	Structure of stainless steel.
3. Mercurous nitrate	100 parts hydrochloric acid; 7 parts mercurous nitrate; 100 parts water.	Heat to effect complete solution, but use cold.	Structure of stainless steel.
4a. Mixed acids in glycerol	1 part nitric acid; 2 parts hydrochloric acid; 3 parts glycerol.	Warm the specimen in hot water before etching. For best results, use the method of alternate polishing and etching. May be used for iron-chromium base alloys containing Al, W, V, and Mo. Proposed by Vilella.	Structure of medium and high carbon iron-chromium base alloys and high speed steels; also high silicon iron alloys (including Duriron).

* These solutions are not generally used but are listed for general information.

Reagent	Composition	Remarks	Used to Show
4b.	1 part nitric acid; 3 parts hydrochloric acid; 2 parts glycerol.	If sufficient time is allowed, this solution will develop the structure of totally austenitic alloys, but better results are obtained by using reagent 4c. This solution etches nickel-chromium alloys satisfactorily. Proposed by Vilella.	Structures of low carbon iron-chromium base alloy, partly austenitic iron-chromium base alloys and Hadfield manganese steel.
4c.	1 part nitric acid; 2 parts hydrochloric acid; 2 parts glycerol; 1 part hydrogen peroxide.	For etching iron-chromium-nickel, iron-chromium-manganese, and all other austenitic iron-chromium base alloys. The amount of hydrochloric acid may be varied if it is found to work too rapidly or too slowly. For best results employ the method of alternate polishing and etching. Proposed by Vilella.	Structure of austenitic iron-chromium base alloys.

Reagent	Composition	Remarks	Used to Show
5. Electrolytic Etching	0.5 grms. sodium hydroxide; 100 cc. water; low current density.	On a 100 volt D. C. circuit use two 4 c. p. lamps in series connected with two wire terminals; preferably platinum wire. Flood the surface of the specimen with the solution. Make contact with one wire at side and dip the other in the solution, moving it around to obtain uniform etching.	Structure of Stellite, high chromium steel, etc.
6. Neutral sodium picrate	Neutral sodium picrate solution.	Wash salt well with distilled water to remove excess picric acid or alkali. Immerse in boiling solution for 20 minutes. Iron phosphide attacked; cementite unattacked. Proposed by Matweieff.	Shows difference between phosphides and cementite.
7. Ferricyanide solution	Use 1 to 4 grms. potassium ferricyanide.	Use hot, freshly made solution. Cementite is blackened, pearlite is turned brown, and massive nitrides remain unchanged. Proposed by Comstock.	

METHOD FOR IDENTIFICATION OF INCLUSIONS IN IRON AND STEEL

By Campbell and Comstock (Modified by Wohrman)

Polish carefully so as to preserve inclusions and project magnified image on ground glass by arc or equally white light without color screen.

GRAY OR BLACK INCLUSIONS

Etch 10 sec. with 10% nitric acid in alcohol

Strongly attacked = Lime Compound from mold wash (rare).

Weakly attacked (slightly pitted or darkened) = Compound Oxide:
(a) either FeO with FeS in solution (usually accompanied by FeO-FeS eutectic)
(b) or FeO + MnO and other oxides in solution.
Note 1. Octahedral crystals are probably magnetite.
Note 2. Both (a) and (b) will be darkened further by 20 sec. sulphur printing (2% H_2SO_4 in water and destroyed by etching with stannous chloride as indicated below.

Attacked
FeS-MnS, rich in MnS.
Note. Reaction not always decisive. Any unattacked FeS-MnS will be blackened by the next treatment.

If Unattacked
Note Color: (1) Very faint pale gray.
(2) Medium or dark gray
and etch 5 min. with boiling alkaline sodium picrate.

CREAM COLORED (PALE YELLOWISH), YELLOW, RED OR PURPLE INCLUSIONS

Etch 10 min. with boiling alkaline sodium picrate

If Unattacked
Etch 5 min. with 10% chromic acid in water. (Be careful to observe that the polished surface is wetted by the solution.)

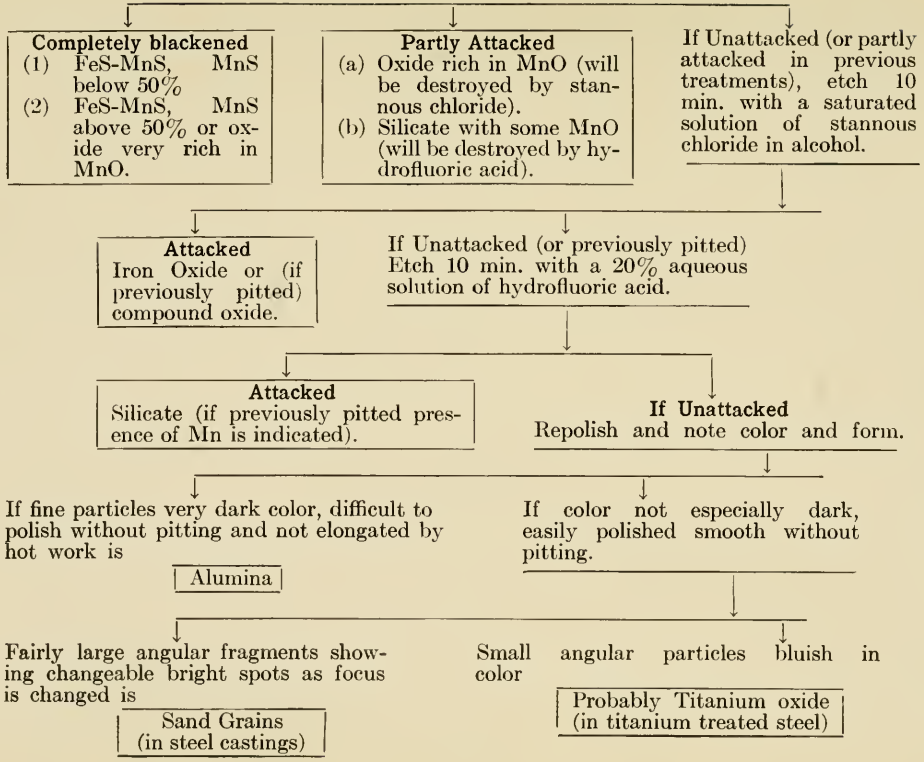
Attacked
Iron Sulphide (pale yellowish)

If Unattacked

Purplish color, rather easily polished smooth, is
Chromium Oxide

Yellow cubes or cubic form is
Zirconium nitride

Pinkish color, strongly angular form rather difficult to polish without pitting is
Titanium cyano nitride



Supplementary Tests

In all instances check your determinations in the light of the evidence of a careful chemical analysis, and, whenever possible, by other methods, such as:

I. **Sulphur printing** (for 20 seconds, using a 2% aqueous solution of H_2SO_4):
   (1) dissolves all FeS-MnS inclusions.
   (2) partly dissolves (pits) FeO containing FeS and oxides of other metals in solution.
   (3) leaves unchanged:
   iron sulphide (pale yellow)
   pure iron oxide (med. gray)
   silicates (dark gray)

II. **Matweieff's Tests.**
   See A. Sauveur's "Metallography and Heat Treatment of Iron and Steel," pages 512 and 513, 1926.

III. **Rohl's Tempering Test for Sulphides.**
   Same reference as in II, page 513.

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APPENDIX C

MICROSCOPES

By W. L. Patterson*

The use of the Microscope in Metallurgy differs somewhat from ordinary uses in that the objects are opaque and must be illuminated from above generally by means of a vertical illuminator.

Any ordinary microscope may be used if proper objectives are available (see objectives). As the metal specimens vary in thickness they must either be mounted at a uniform height or the illuminating device must be attached to the vertical illuminator to move with it when focusing.

The usual table or students microscope used for the examination of metal has an adjustable stage to provide for differences in thickness.

In both of the forms described the specimens must be mounted with the polished side up and levelled so that the face of the specimen is perpendicular to the optical axis of the microscope.

Where many specimens are to be examined and highest powers used as in research the inverted form of microscope is to be preferred. In this form the stage is above the optical parts and the specimen is placed upon the stage with the polished side down.

Objectives

The objectives (the lens nearest the specimen) are especially made for this work by being corrected for use without coverglass. This difference is scarcely noticeable on power of sixteen millimeter or less in focus but in the higher powers the definition is poor unless properly corrected objectives are used.

Objectives are made in a variety of focal lengths such as 48, 32, 16, 8, 4 and 2 millimeters and their initial magnifying powers are 2, 4, 10, 20, 43 and 100 respectively. By initial power is meant that the objective alone gives an image of certain magnification which in turn is again magnified by the eyepiece. We thus have the compound microscope. These initial magnifications vary in accordance with the distance between the eyepiece and the objective the greater the distance the greater the magnification.

While this might seem a ready means of increasing or decreasing the magnification it does not prove successful in practice as the lenses are mathematically calculated to produce the best images at a particular distance. This distance is known as tube length and varies with different makers and on different types

* Mr. Patterson of the Bausch and Lamb Optical Company, Rochester, New York, very kindly wrote this article at the author's request.

of microscopes. The objectives are usually engraved with the tube length for which they are corrected and this distance is found by measuring the length of the tube from the shoulder against which the objectives screws to the shoulder against which the eyepiece rests.

The resulting magnification is the product of the objective power and the eyepiece power. (See eyepieces.)

These magnifications are based on the observation of a vertical image appearing at a distance of 250 millimeters in front of the eye, when looking into the microscope. They may be checked by projecting a real image at 250 mm. from the eyepiece.

Eyepieces

The eyepiece (lens nearest the eye) is used to magnify the image formed by the objective. Eyepieces are made in focal lengths of 50, 40, 33, 25, 20, 16 mm. with magnifications of 5, 6.4, 7.5, 16, 12.5 and 15 respectively. As stated under objectives it is the power of the objective multiplied by the power of the eyepiece, at correct tube length, which gives the total power of the microscope. Thus a 16 mm. focus objective of 10X with an eyepiece of 25 mm. focus of 10X gives at 160 mm. tube length a magnification of 100 diameters.

Vertical Illuminators

Vertical illuminators in common use are of two forms, the plane glass which covers the entire aperture of the objective and reflects light down through the objective to the specimen and at the same time permits the light to pass through it to the eyepiece and eye. This gives true central illumination and is preferred by many.

The second form consists of a mirror or prism covering part of the objective aperture the light going to the specimen through one side of the objective and returning on the opposite side. This gives an angular illumination and is useful in bringing out in relief parts of the specimen which may be above or below the principal surface.

Illuminants

Illuminants for metal examinations are usually the incandescent lamp or the arc lamp. The former is nearly always used in table work and may be used in photography although due to its less intensity longer exposures are required than with the arc. Only incandescent lamps with very compact filament should be used if good results are to be obtained. The ribbon form of filament is the best, other concentrated forms may be used but as the illuminant is usually focused upon the specimen the scattered filament gives an uneven illumination.

The arc lamp consists of two carbons automatically fed together as they consume and the light is taken from the crater of the upper carbon. Direct current should always be used with the arc lamp if available and if not available it is probably best to use the incandescent lamp.

Cameras

Any camera can be used to make a picture with the microscope but due to the necessity of solidity, proper centering, etc., it is best to use a camera especially made for photo-micrographic work.

The ultimate goal of every metallographer should be toward a complete outfit meeting all the requirements for the finest work. The illustration shows one of this type where all parts are built for this particular work. See Fig. 4.

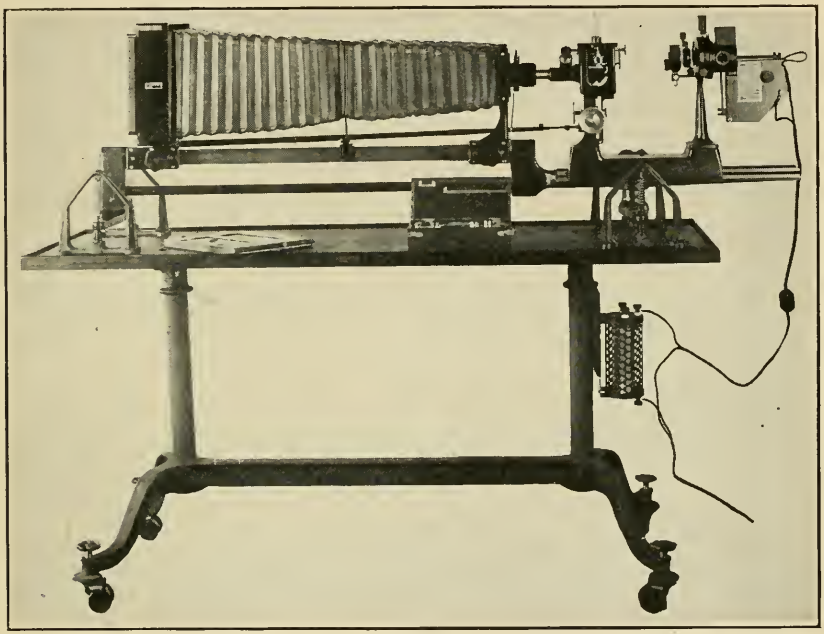

Fig. 4

The microscope is of the inverted type. The holders for objectives and eyepieces are at a fixed distance (tube length) and solid. The specimen is inverted upon the stage and moved by mechanical means and due to the solidity of the stand the specimen may be of nearly any size and weight within reason. A focusing mechanism extends from the microscope to the ground glass at the rear of the camera. The illuminant, a 90 degree automatic arc lamp, and the condensers all firmly attached to the microscope to insure correct centering and separation at all times. The camera is solid and can be used for all magnification and sizes of plates. Shock absorbers are provided to guard against vibrations usually found in industrial laboratories.

APPENDIX D

PHOTOMICROGRAPHY*

By Walter M. Mitchell† and H. M. Boylston‡

The photomicrography of polished and etched specimens of metals with the aid of a microscope is important as a means of securing records of their microstructure for reference and future examination. The production of such photographs, called photomicrographs (not microphotographs, which are merely photographs of microscopic size), requires proper care and skill in the manipulations, if satisfactory results are to be obtained. Before photomicrographic work is attempted, four things are essential:

(*a*) The microscope and the source of illumination must be in proper adjustment, individually and with each other.

(*b*) The microscope must be so mounted that it will be free from vibration. Ordinary vibrations are harmless if all parts of the apparatus are tightly clamped together.

Vibrations from steam hammers and from railroad trains passing close to the laboratory can be minimized by placing several inches of sponge rubber under the legs of the stand. If this does not correct the trouble the outfit may be suspended from the ceiling with spiral springs, or a spring suspension stand may be used.

(*c*) Specimens must be polished flat and free from scratches.

(*d*) If the specimen is etched, the structure should be as clean cut as possible. Lighter etching than that used in low power work is necessary for good results at high magnifications.

Magnifications. — It is recommended that the following standard magnifications be used in making photomicrographs (expressed in diameters): for ferrous materials, 10, 50, 100, 250, 500, 1000, 2000, 5000; for non-ferrous materials, 10, 25, 50, 75, 100, 150, 200, 250.

The term photomacrograph is generally applied when the magnification is less than 10 diameters. In photomacrography the following magnifications are commonly used (expressed in diameters): $\frac{1}{2}$, 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, 3, 5.

Generally speaking, it is better to use a higher power objective rather than a lower for obtaining a given magnification if maximum resolution is desired, but too short a bellows length (projection distance) is also to be avoided.

* Printed from the American Society for Steel Treating handbook, by permission.

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‡ H. M. Boylston is professor of metallurgy, Case School of Applied Science, Cleveland, Ohio.

Lenses. — In the following table are given the various lenses and lens combinations which are convenient for obtaining different magnifications.

Lenses for Various Magnifications

Linear Magnification in Diameters	Objective		Ocular
	Type	Focal Length (approximately) mm.	Type*
½ to 2	Photographic Tessar IIb	153	None
2 to 10	Photographic Micro-Tessar or Micro-Planar	72	None
10 to 20	Photographic Micro-Tessar or Micro-Planar	48	None
20 to 30	Photographic Micro-Tessar or Micro-Planar	32	None
30 to 75	Achromatic	32	Huyghens or similar
75 to 150	Achromatic	16	Huyghens or similar
200	Achromatic or Apochromatic	8	Compensating or projection eyepieces for use with apochromats
200 to 500	Achromatic or Apochromatic	8 4	.....
1000 to 5000	Oil Immersion	2	.....

* The magnifying power of the ocular should be such that the desired size of projected image can be obtained with a moderate length of bellows.

Determination of Magnification. — Where extreme accuracy is desired, magnifications should be measured experimentally with the aid of a stage micrometer. This is preferably made of metal and placed on the microscope stage in place of the specimen. The image of the rulings on the micrometer is then projected on the focusing screen and the magnification determined directly by means of a small scale, either ruled on the focusing screen or placed over it. Stage micrometers ruled to 0.1 and 0.01 mm. are the most convenient. The projection distance is the distance in millimeters or inches from outside focus of eyepiece lens to nearest (ground) surface of focusing screen. Charts may readily be prepared for any combination of eyepiece and objective with the projection distance as one co-ordinate and magnification as the other.

For approximate determination of magnifications which are sufficient for routine work the following formula may be used:

$$M = \frac{DM'}{250}$$

where M is the magnification to be determined, D the projection distance measured in millimeters, and M′ the magnification of a particular combination of eyepiece and objective at 250 mm. (10 inches) projection distance. The values of M′ are generally supplied by the manufacturer in a table accompanying the microscope, and may be given as the magnification at the eye, since the lens of the eye produces on the retina an image with a magnification corresponding to that obtained in projection at a distance of 250 mm. from the outer focus of the eyepiece. Since this outer focus of the eyepiece is very close (about 3 mm. away) to the lens of the eyepiece the projection distance may be measured roughly by determining the distance from the eyepiece lens to the near side of the focusing screen.

Illumination of Specimens. — For use with objectives of 32 mm. focal length or less, all of which are used in combination with oculars, vertical illumination (i.e., normal to the surface under observation) is usually necessary. Either the plane-glass or mirror type of illuminator (the latter including the totally reflecting prism) in which the reflector is placed between the objective and the ocular may be used. For the best results, the condition of "critical illumination" should be obtained; that is, the optical distance from the source of light (real or apparent) to the surface of the specimen should equal the distance from the specimen to the focal plane of the ocular, or, in other words, the source of light should be approximately imaged on the specimen. The mirror or prism type of illuminator is not suitable for very short focus objectives (4 mm. or less), since it obscures a relatively large portion of the lens aperture.

With objectives of the photographic type, vertical illumination is obtained by inserting the illuminator (plane-glass) between the lens and the surface of the specimen. Oblique illumination may be obtained by directing a beam of light so that it strikes the surface of the specimen obliquely or, in a lesser degree, by rotating the reflector of the vertical illuminator. A special form of oblique illumination known as "conical illumination" and methods for obtaining it are described by H. S. George in the Transactions, A. S. S. T., Vol. IV, 1923, page 140.

For lenses of the photographic type of more than 48 mm. focal length the illumination should be diffused, for example, daylight, or oblique, as obtained by directing a beam of light upon the specimen obliquely from one side; or vertical, by means of a large plane-glass placed between the lens and the object. In order to increase the size of the field, which otherwise would be restricted in diameter to that of the photographic lens, a relatively large plano-convex lens should be placed between the reflecting plane-glass and the source of light, the lens being located so that the optical distance between it and the photographic lens equals the focal length of the plano-convex lens. Moistening the surface of the specimen with water, glycerin or oil, or even immersing the entire specimen in alcohol or water, will often be found desirable for the purpose of increasing the contrast in the photograph.

In the case of fractured specimens, a good reproduction of the fractured

surface may be readily obtained by using two sources of artificial light of unequal intensities. Place one source of light on each side of the specimen. A reflector may be used in place of the weaker light source if desired. The second, or weaker, illuminant serves to neutralize partially the deep shadows cast by the stronger one and so produces a good relief effect.

Photographic Plates. — The most convenient size of plate or film for the average laboratory is 4 × 5 inch, but economy may be effected where a great many negatives are made daily by using a size $3\frac{1}{4} \times 4\frac{1}{4}$ in h. Occasionally a 5 × 7 inch negative or even an 8 × 10 inch negative will be advantageous, especially in macrographic work.

Various types of plates are listed below because of the difficulty in some localities of obtaining some preferable types. It is simpler and easier, however, to learn how to use one plate or film to the best advantage and stick to it. The Wratten M (panchromatic) plates have a special fine grained emulsion which gives a very desirable combination of detail and contrast. This detail and contrast may be varied according to requirements by the use of monochromatic color screens. The Wratten filters, or screens, are as follows: B (green), F (red), K (yellow), etc. Nothing is gained by using these plates unless a monochromatic screen is used in conjunction with them.

While it is necessary, for the best results, to handle and develop Wratten M plates in complete darkness, the makers include in each box of plates a card giving the proper time of development for that particular emulsion. Allowance is made for low contrast, normal contrast, great contrast and varying temperatures of developer; thus an opportunity is afforded for the exercise of judgment on the part of the operator depending upon the conditions surrounding the making of the negatives. There are other panchromatic plates but they do not give as good results.

One of the disadvantages of panchromatic plates is their poor keeping qualities, especially in warm weather.

The following brands of orthochromatic (isochromatic, i.e., sensitive to yellow light) plates may be used in conjunction with yellow or green screens with complete satisfaction, but they cannot be used with a red filter:

Medium Speed: Standard Orthonon; Cramer Medium Iso; Stanley; Hammer Special Nonhalation Ortho.

Slow Speed: Cramer Slow Iso; Hammer Slow Ortho.

These plates are of average contrast, fine grained, and may be used for structures which show considerable contrast.

Plates giving greater contrast but requiring slightly longer exposure are:

Medium and Slow Speed: Cramer Commercial Isonon; Stanley Commercial; Hammer Commercial Ortho.

Photographic Films. — The use of films for photomicrographic work has much to commend it. The cut films are easily handled in frames which hold them flat in the ordinary plate holder. Other frames of special non-corrodible material are available for holding the films in the developer tank and fixing box. Films do not crack or break during storage or shipment and take up

less space. They apparently stay flat during exposure since the negatives do not show "out of focus" areas. They are not yet available in the Wratten M emulsion but can be had in the Standard Orthonon type, and should be used in conjunction with a Wratten B or a K filter for the best results.

Monochromatic Filters. — Since all photographic plates are most sensitive to blue light, for which the objective lenses are not corrected, and since the yellowish green rays are those most easily distinguished at the focusing screen, it is necessary to absorb the blue rays with a suitable color screen or filter. Through their use a good achromatic lens gives just as good or better results as an expensive apochromat. Moreover, apochromatic lenses always have a residual spherical aberration resulting in lack of flatness of field in spite of so-called compensating eyepieces. Most American achromats are corrected for the very color obtainable with a Wratten B (green) filter, so the latter is obviously the correct one to use in conjunction with a plate which is sensitive to green light, such as the Wratten M or the Standard Orthonon, Cramer Iso or Hammer Special Nonhalation Ortho. Some prefer a Wratten K_1, K_2 or K_3 filter, while others prefer the Wratten M plates and the Wratten B (green) screen. If the exposure is correct (and there is considerable latitude allowed) and the development correct, any gradation of detail and contrast may be obtained with this combination at low, medium or high magnification. The green color is also the most restful to the eye in visual work especially if a white ground screen is used in combination with it.

Red screens (Wratten F) give more contrast and somewhat less detail than green (Wratten B) and are preferable in macrography where minute detail is less important than maximum contrast.

Theoretically, it would seem as if a blue filter (short wave length) in conjunction with a proper plate would give better results where fine details are to be photographed at high magnification, but this does not appear to be borne out in the experiences of many of the most careful workers. Light of short wave length may have its advantages in the case of stained transparent objects using transmitted light, but it appears to offer no special advantage in metallography.

For the best results the filter used should be kept in place while adjusting the final focus at the focusing screen.

Some workers use a liquid filter such as a nickel chloride solution for green, or one of the green Aniline dyes, and for a yellow filter a saturated solution of potassium bichromate, but it is difficult to keep the solutions free from air bubbles and at the proper strength because of evaporation. A well made glass filter will last indefinitely if maintained at a point in the beam of light where the heat from the light is at a minimum.

Exposure of Negative. — The time of exposure varies with the following factors:

(*a*) *Character of Specimen.* — Bright or light colored structures, such as free ferrite or free cementite, require shorter exposures than dark ones like troostite, sorbite, pearlite, etc., and generally speaking, the darker the general appear-

ance of the structure and the less contrast it contains the longer will be the proper time of exposure.

(*b*) *Speed of Plate.* — The faster the plate, the shorter will be the exposure required.

(*c*) *Intensity of Light.* — With a good carbon arc light and with iris diaphragms and settings of the optical system arranged to give critical illumination, the exposure required at 100 diameters magnification using direct current, a Wratten M plate and a Wratten B filter is approximately eight seconds. With alternating current under the same conditions the required exposure is twelve seconds. With a tungsten arc light which can be used only with direct current, and other conditions as stated, the required exposure is about forty-five seconds. With a 6 volt, 24 watt, automobile headlight type of Mazda incandescent lamp the corresponding exposure would be about sixty seconds.

(*d*) *Color of Light.* — If the proper exposure with carbon arc and green (Wratten B) filter at 100 diameters is eight seconds, the exposure under similar conditions with a red (Wratten F) filter would be approximately six seconds for a Wratten M plate. For a yellow filter (K_2) and other conditions the same as stated the exposure would be approximately four seconds.

(*e*) *Magnification Used.* — If the exposure required at 100 diameters is eight seconds the exposure required at 400 diameters would be approximately forty seconds or at 1000 diameters it would be approximately sixty seconds.

(*f*) *Size of Opening in Iris Diaphragms.* — The size of the opening in the iris diaphragm between the source of light and the first condenser in most American instruments controls, to a considerable degree, the resolution of detail in the image; the smaller the opening the greater the resolution, but it is also true that the smaller the opening the longer the exposure.

If the correct exposure time has not been obtained from the information given above then this should be determined by experience and trial. Adopt a system of making all exposures at standard magnifications of, say, 50X, 100X, 500X, 1000X, 2000X, 5000X. If this is done, after a little experience, the proper exposure time can be estimated by the appearance of the image on the focusing screen. The correct exposure time may be easily determined by exposing successive portions of a test plate to progressively longer exposures. Draw slide out of the plateholder so as to expose one inch of the plate, expose for 5 seconds, draw the slide out another inch, expose again for 5 seconds, and repeat until the whole plate is exposed. On developing, that strip which is correctly developed will indicate the proper exposure time. In any case the exposure should be sufficiently long so that the darker portions of the structure will be fully exposed; otherwise no details in these will be recorded and they will appear dead black in the final print.

Plate Developers. — The safest and most convenient developer is generally that recommended by the plate or film manufacturer who is in a position to know what developer is best suited to the particular emulsion furnished. Directions are generally given on a card or pamphlet found inside the box of plates or films.

The developer recommended by the manufacturer of Wratten M plates is as follows:

PYRO SODA DEVELOPER

Developing Formula for Wratten and Wainwright M Plates

Do not wet the film before applying developer

		Avoirdupois	Metric
A.	Potassium Metabisulphite	250 grains	17 grams
	Sodium Sulphite (desiccated)	2½ ozs.	70 grams
	Pyrogallic Acid	¾ oz.	20 grams
	Water to	32 ozs.	1000 cc.
	Dissolve in order given.		
B.	Sodium Carbonate (desiccated)	2⅔ ozs.	75 grams
	Potassium Bromide	15 grains	1 gram
	Water to	32 ozs.	1000 cc.
	Use equal parts of "A" and "B."		

Typical Time of Development with above Formula in Minutes.
Time varies somewhat with different batches of plates.

Temperature	Diminished Contrast	Normal Contrast	Great Contrast
50 degrees Fahr.	2.0	3.2	6.4
65 degrees Fahr.	1.0	1.6	3.2
80 degrees Fahr.	.5	.8	1.6

Pyro developers are readily adapted to tank or time development and it is nearly impossible to overdevelop with them.

For other plates and films the choice of a developer is largely a matter of personal preference.

The two developer formulæ which follow, the result of many trials and experiments, are a normal developer for general work and a contrast developer, which will give maximum contrast, for contrast and lantern plates. They are recommended as having good keeping qualities, working rapidly, free from stain, and inexpensive to prepare.

Make up a stock solution as follows:

NORMAL PLATE DEVELOPER

		Avoirdupois	Metric
A.	Water (distilled)	32 ozs.	1000 cc.
	Sodium sulphite (desiccated)	1 oz.	30 grams
	Metol or Elon	60 grains	4 grams
	Hydrochinone	60 grains	4 grams
	Potassium bromide	30 grains	2 grams
B.	Water (distilled)	32 ozs.	1000 cc.
	Sodium carbonate (desiccated)	¾ oz.	22 grams

Dissolve Elon before adding sodium sulphite; otherwise it may be reprecipitated: add other ingredients in order given.

For a working strength developer, use equal parts of A, of B, and of water.

Contrast Plate Developer

		Avoirdupois	Metric
A.	Water (distilled)	32 ozs.	1000 cc.
	Sodium sulphite (desiccated)	$2\frac{3}{4}$ ozs.	80 grams
	Hydrochinone	$\frac{1}{2}$ oz.	15 grams
	Potassium bromide	$\frac{1}{4}$ oz.	8 grams
B.	Water (distilled)	32 ozs.	1000 cc.
	Caustic potash	$1\frac{2}{3}$ ozs.	48 grams

For a working strength developer, use equal parts of A, of B, and of water. Ordinary tap water may be used if free from iron salts.

The stock solution will keep indefinitely if stored in well filled, tightly corked bottles.

Either of the above developers in mixed solution may be used until exhausted, 5 ounces of the mixed solution being sufficient for one-half dozen 4×5 inch plates or their equivalent. Developer should be used at a temperature of 65 degrees Fahr. This is very important, since higher temperatures will give failure due to "frilling" of the emulsion. At 65 degrees Fahr. development of a properly exposed plate will be complete in 3 to 5 minutes; longer time will increase the density of the negative, necessitating longer printing time, and increase the contrast. Insufficient development under above conditions indicates underexposure.

After the plates are developed they should be rinsed thoroughly in water and fixed in the following fixing bath:

Chrome Alum Fixing Bath

	Avoirdupois	Metric
Water	32 ozs.	1000 cc.
Hypo	12 ozs.	350 grams

When dissolved, add $1\frac{2}{3}$ ozs. (50 cc.) of the following hardening solution:

Water	$3\frac{1}{2}$ ozs.	100 cc.
Chrome alum	185 grains	12 grams
Sodium bisulphite	308 grains	20 grams

This bath ceases to harden the gelatine film after keeping for several days, so that in warm weather if the film tends to soften a fresh fixing bath should be prepared daily.

In cold weather use one-half the quantity of hardening solution. If precipitation of dirty white and finely divided sulphur occurs, as sometimes happens while mixing or on long standing, it is better to throw the bath away and prepare a new one. Do not use old or discolored fixing baths.

The following fixing bath, although it will not harden the gelatine film as

much as the chrome alum bath, maintains its hardening properties on keeping and is, therefore, preferable for use in hot weather.

Fixing Bath for Hot Weather

	Avoirdupois	Metric
Water	64 ozs.	2000 cc.
Hypo	16 ozs.	500 grams

When dissolved, add the following hardening solution:

Water	5 ozs.	150 cc.
Alum (powdered)	1 oz.	28 grams
Sodium sulphite (desiccated)	1 oz.	28 grams
Glacial acetic acid	1 oz.	30 cc.

When using the above solution, fixing will take about double the time (20 minutes as a minimum) required to dissolve the unreduced silver emulsion, which is determined by noting when the grayish white color disappears from the back of the negative. After thoroughly fixing, negatives should be washed for one-half hour in running water to remove all traces of hypo, then stood on a drying rack so that they will drain from one corner. Films should be suspended from one corner to dry.

A convenient test for determining whether washing is complete, which may also be used for prints, is made as follows:

Test for Completion of Washing

	Avoirdupois	Metric
Water	8 ozs.	240 cc.
Potassium permanganate	8 grains	$\frac{1}{2}$ gram
Sodium carbonate	10 grains	$\frac{2}{3}$ gram

Allow the excess water to drain from the partially washed negative or print into a graduate and add a few drops of the above solution. If the color remains pink, washing has been complete; but if it turns yellowish, hypo is still present. This is a very sensitive test and is useful where speed is necessary.

Over- and Under-Exposed Negatives. — Underexposed negatives will lack detail in parts corresponding to the darker regions of the specimen, while overexposed will be "flat"; i.e., full of detail without much contrast. Whenever possible, it is better to repeat the exposure, making another negative giving double, or half the exposure time, as the case may be, than to attempt to "doctor" a poor negative. Nothing can be done with underexposure, as detail lacking in the negative originally cannot be introduced by any chemical process. Contrast may be increased in overexposed negatives, but the process is uncertain and the intensified negative is rarely permanent. Repeat the exposure, or use a contrasty paper when making prints.

Overdeveloped negatives are very dense, requiring a long time in printing. These may be reduced in the following solution:

Reducing Solution

	Avoirdupois	Metric
A. Water	1 oz.	30 cc.
Potassium ferricyanide	15 grains	1 gram
B. Water	32 ozs.	1000 cc.
Hypo	1 oz.	28 grams

Mix A and B and immerse the plate in the solution until sufficiently reduced. Wash thoroughly and dry in the usual manner. The above solutions (A and B) keep well, but the reducer obtained by mixing A and B will remain active for only a short time.

Printing. — Prints are made from the negative in the usual way. Use a constant light source and always place the printing frame at a constant distance from it (18 inches for a 100 watt bulb). The proper exposure for the print may easily be estimated from the density of the negative after a few trials. If many prints are to be made a special printing machine is a good investment.

Satisfactory papers are Azo, Cyco, and Velox. Azo is somewhat slow to print but is cheap in price and easy to work with, and an excellent paper for general use. It is made in four grades, Nos. 1 to 4. The latter gives most contrast and is recommended for the average negative. Cyco prints more rapidly than Azo and is made in three grades: Contrast, Normal and Soft. The former is very contrasty, and the latter very soft and intended for very contrasty negatives. Normal Cyco is for general use and is about equivalent to No. 3 Azo. Velox is made in four grades in the same order as Azo. It is more expensive than Azo and has no advantage over it. It is to be remembered that "hard" or "contrasty" papers are to be used for "soft" or "flat" negatives, and vice versa. Always use paper with glossy surface.

There is no single developer that will give the best results with all makes of papers. It is safe to use that recommended by the maker of the paper. For the above mentioned papers, the following may be relied upon to give good results.

Make up a stock solution as follows:

Dissolve in the order given:

	Avoirdupois	Metric
Warm water (distilled)	16 ozs.	500 cc.
Sodium sulphite (desiccated)	$1\frac{1}{4}$ ozs.	35 grams
Metal or Elon	30 grains	2 grams
When completely dissolved, add:		
Hydrochionone	120 grains	8 grams
Sodium carbonate (desiccated)	$1\frac{3}{4}$ ozs.	50 grams
Potassium bromide	15 grains	1 gram
Sodium citrate	15 grains	1 gram

Dissolve Elon in water before adding sodium sulphite; otherwise reprecipitation may occur.

This is a concentrated solution which will keep for months in filled, tightly corked bottles. For a working solution, dilute with 2 parts water for hard or contrasty papers or with 4 parts for normal and soft papers. Temperature of developer should be 65 degrees Fahr.

Contrasty papers should develop quickly, 20 to 40 seconds, while soft and normal papers will develop more slowly, 40 to 60 seconds. The printing exposure should be so adjusted that development will be complete in the times specified. Too short exposure will require long development, giving cold, bluish tones; too long exposure will cause prints to flash up and darken before they can be removed from developer, giving muddy olive tones. If altering the exposure time does not remedy this, the addition of a few grains of caustic potash or soda to the developer will remove olive tones, and a few drops of 10 per cent solution of potassium bromide will correct blue tones.

When prints are fixed in the fixing bath given above, 10 minutes are sufficient provided they are kept in motion. After fixing, wash in running water 30 minutes, or until permanganate test shows absence of hypo. Dry prints on a ferrotype plate or "squeegee board" by placing them with surface down, covering with blotters and pressing into firm contact with a print roller. However, if the wash water is dirty or contains sediment, swab each print clean with a tuft of wet cotton before placing on ferrotype plate. When dry the prints may easily be stripped off, and will have a brilliant glossy surface which is very pleasing and which will show the finest details of the negative. Ferrotype plates should be kept clean and free from scratches. They may be washed with soap and water if necessary. Any tendency of prints to stick to the ferrotype plate may be overcome by rubbing its surface with a drop or two of three-in-one oil or paraffin dissolved in benzine, and polishing with a tuft of clean dry cotton or a soft cloth.

Trimming of Prints. — This is most easily done with a knife edge print trimmer to a size $3\frac{1}{2}$ inches square or any other convenient size. Some prefer a circular shape and this can be done by cutting the dry print with a revolving print trimmer and a metal mask. Care must be used with this method to avoid rough edges on the print. Circular prints may also be made on square sheets during printing, by placing a mask made of red or black paper between the negative and the light. If the printing mask is used it should not be placed between the negative and the paper. In the latter position, fine detail may be destroyed.

General Precautions. — Have a separate room set aside to be used for the dark room and for no other purpose. It should be provided with a wide bench along one wall with sink and running water at one end. A "safe light" over the sink and another at the other end of bench will be convenient, the latter for loading plate holders. Dust off plates with a soft camel's hair brush before loading, to prevent pinholes in the negative. Keep things in order, with a place for everything and everything in its place. Store negatives in paper envelopes with number, description and other data on each one, and with a catalog so that a given negative can be found quickly when wanted. Cleanli-

ness is essential. Do not allow dried developer to collect around necks of bottles. Have a special tray or hard rubber fixing box for the fixing bath and use it for no other purpose. Never use a hypo tray for developing. Rinse fingers and hands after handling prints in fixing bath before again using the developer. Hypo is an excellent thing in a fixing bath, but a very bad one in the developer. If developers or fixing bath get spilled, wipe them up and do not allow dried crystals to blow around the dark room. In warm weather put developing tray into a larger one containing ice water and thus keep solutions at their proper temperature.

If possible printing should be done in a separate dark room where an orange or dark yellow light will suffice. An electric fan is a great convenience for hastening the drying of negatives and prints.

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APPENDIX E (a)

STANDARD DEFINITIONS OF TERMS RELATING TO METALLOGRAPHY*

Serial Designation: E7-27

Issued as Tentative, 1921; Adopted in Amended Form, 1924; Revised, 1927.

Alloy. — A substance, having metallic properties, consisting of two or more metallic elements, or of metallic and non-metallic elements, which are miscible with each other when molten, and have not separated into distinct layers when solid.

Note: Alloys when solid may be composed of eutectics, eutectoids, solid solutions, chemical compounds, or of aggregates of these components with each other or with pure metals. In the commercial sense, the term "alloy" would also include the case where some separation into distinct layers had occurred.

Etching Reagent. — A substance or reagent used to reveal the structure of a metal or alloy causing a difference in the appearance of different constituent parts or different grains.

Note: This substance is usually a solution of the reagent in water, acid or alkali, but etching may in some cases be brought out by a differential oxidation produced by "heat tinting."

Equiaxed Grain. — A grain which has approximately equal dimensions in all directions.

Note: This term is practically restricted to unstrained metals.

Grain. — A term used for an allotrimorphic crystal present in metals and in one-component alloys.

Note: Although a crystal may show division by "twinning," etc., it is regarded as the grain rather than smaller sub-divisions. In the case of alloys of more than one component, the crystal which, by its transformation, gave rise to these constituents is taken as the grain when its limits are still discernible; if the limits are not discernible the individual constituents are considered as grains.

Grain Size. — This is preferably expressed as the number of grains per unit area of cross-section. The average cross-sectional area of the grain may also be given or the average dimensions. Grain size of strained material is expressed

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by the average number per linear unit in two directions, or by the average number per unit cross-sectional area, together with the ratio of length to breadth (L/B).

Note: By the "Intercept" Method for grain count, the number of grains and fractions of grains along a line of known length on two axes at right angles to each other are counted. By the "Planimetric" Method for grain count, the number of grains and fractions of grains within a definite area are counted.

Macrograph. — A graphic reproduction of any subject which has not been magnified more than 10 diameters.

Note: When it is desired to indicate that it is a photographic reproduction, the term "photomacrograph" may be employed.

Magnification. — The ratio of the size of the image to that of the object.

Note: Magnification is generally expressed in "diameters," thus "×100" or "100 diameters."

Metal. — Any of the metallic elements, either of very high purity or of ordinary commercial grades.

Note: Brass and many other alloys are metals in the commercial sense, but alloys in the scientific sense.

Metallography. — That branch of science which relates to the constitution and structure, and their relation to the properties, of metals and alloys.

Micrograph. — A graphic reproduction of any object magnified more than 10 diameters.

Note: When it is desired to indicate that it is a photographic reproduction, the term "photomicrograph" may be employed.

APPENDIX E (b)

DEFINITIONS OF OTHER METALLOGRAPHIC TERMS

By Prof. H. M. Boylston*

When specimens of iron and steel (and other metals and alloys) are suitably polished and etched with dilute acids or other special reagents, certain characteristic crystalline formations are observable under the microscope. In most cases they correspond (in the case of iron and steel) to various fields on the iron-carbon equilibrium diagram, shown in Fig. 5. The following defini-

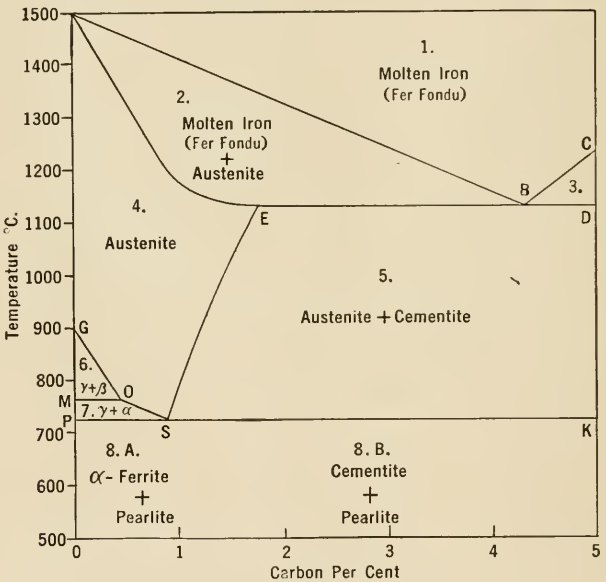

Fig. 5. Iron-Carbon Diagram.

tions of these constituents include their constitution, microstructure, occurrence, and normal position in the iron-carbon diagram.

Allotriomorphic Crystals. — When the free development of crystals is hindered by unfavorable crystallizing conditions, as, for example, contact with other crystals, likewise in process of formation, the regular external form is

* Prof. Boylston has given the author permission to reproduce these definitions, published in the "Engineers," 1928.

not preserved and the resulting imperfect crystals are called allotriomorphic crystals or occasionally "anhedrons" or faceless crystals. They are frequently called "crystalline grains" or "grains" (Sauveur).

Allotropy. — That property of certain substances by virtue of which their physical properties are suddenly and markedly changed at certain temperatures known as transformation temperatures, without a change in chemical composition. Two allotropic forms of carbon are diamond and graphite. The allotropic forms of iron are thought to be alpha, beta, gamma, delta, although some doubt the existence of the beta form and some believe that the alpha and delta allotropic forms are identical. This term should not be confused with polymorphism, which is the property of some substances by virtue of which they crystallize in more than one form. Some use these terms as synonyms.

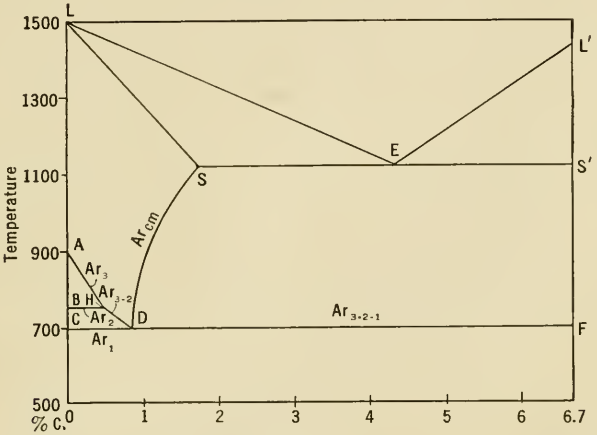

FIG. 6. Equilibrium diagram of Iron-Carbon Alloys. Reproduced by permission from Sauveur's Metallography and Heat Treatment of Iron and Steel.

Austenite is a solid solution of iron carbide, Fe_3C (or of C?) in gamma iron. It occurs above *GOSK* in Fig. 5 (*AIIDF* in Fig. 6) and probably in regions 6 and 7 (Fig. 5). It is retained when cold in some high-carbon alloy steels and in some high-alloy iron-alloys, especially after rapid cooling. Under the microscope it appears as polyhedral grains. It has a face-centered space lattice.

Cementite is the definite carbide of iron (Fe_3C) and the hardest constituent. It contains 6.67% carbon. It occurs free in commercial plain carbon steels containing more than 0.85% carbon, and forms $12\frac{3}{4}$% by weight of pearlite. It is normal in regions 3, 5, 8A and 8B (Fig. 5). It appears as white, brilliant masses, networks, globules, or needles when free, or as the bright laminæ in pearlite. Free cementite is also called "excess," "massive," "non-eutectoid," or "surplus" cementite, while the cementite included in pearlite is called "eutectoid cementite" or "pearlite-cementite."

Crystals. — An arrangement of atoms forming small solids of regular geometrical outlines, such as cubes, octahedra, etc. (Sauveur.)

Dendrites. — Crystalline groups or aggregates of allotriomorphic crystals arranged in distinct forms usually described as "tree-like," "fern-leaf," "pine-tree," etc. (Sauveur.)

Eutectic Alloy. — The word eutectic means "well melting." A eutectic alloy is that alloy in any series which has the lowest melting point of that series; the melting point is constant and occurs at a temperature known as the eutectic temperature. Eutectic alloys have a characteristic microstructure consisting of alternating laminations or a series of regular dots or rods occurring on a plain background.

Eutectoid Steel. — Steel made up exclusively of pearlite or having such a content of carbon (0.90% in pure iron-carbon alloys, approximately 0.85% in commercial steels) that it would be made up exclusively of pearlite if slowly cooled from above the critical range.

Ferrite. — Ferrite is nearly pure iron. It may contain in solid solution such impurities as carbon (up to 0.05%), silicon (up to 4%), phosphorus (up to 1.7%), nickel, copper, vanadium, molybdenum, tungsten and chromium in small amounts when in the alpha state. It is thought to exist in four allotropic forms: alpha, beta, gamma, and delta. Alpha iron is the softest constituent in iron and steel, and the principal one in ingot iron, wrought iron and low-carbon steel. It forms the dark laminæ of pearlite of which it forms $87\frac{1}{4}\%$, by weight. It is found in regions 6, 7, 8A and 8B in Fig. 5. When free, alpha iron exists as polyhedral grains surrounded by dark networks.

Graphite. — Graphite is carbon crystals seen in the form of curved or spiral plates in gray or mottled cast iron. It is also found in rounded masses or "rosettes" in malleable cast iron, and in this form also is thought to consist of minute carbon crystals. It is normal in regions 3, 5, 8A and 8B in Fig. 5 when the alloys are very slowly cooled and especially if much silicon is present. It is also found in the rosette form, occasionally, in high-carbon tool steels, especially if the silicon be high (over 0.50%) or if there be any nickel present, in the absence of chromium. In such cases it is produced by annealing and ruins the steel.

Hyper-eutectoid Steel. — Steel which contains more than 0.85% carbon and hence normally contains some free cementite after slow cooling from above the critical range.

Hypo-eutectoid Steel. — Steel which contains less than 0.85% carbon and hence normally contains some free ferrite after slow cooling from above the critical range.

Inclusions. — Solid non-metallic substances mechanically embedded in metals or alloys.

Manganese sulphide (MnS) occurs in iron and steel containing more than a trace of sulphur. It appears under the microscope as round (in castings) or lenticular (in worked metal) dove-gray spots.

Martensite (constitution disputed) is the principal constituent of hardened and untempered steels and is harder than austenite, troostite, or sorbite. Sauveur and others believe it to be an aggregate or mechanical mixture of a solid solution of carbon in supercooled gamma iron and of a supersaturated solution of carbon in alpha iron. Under the microscope it is seen as dark needles arranged indistinctly in equilateral triangles, and at very high magnifications, a still darker midrib of troostite (?) is distinguishable.

Neumann Bands. — Mechanical twins appearing as a number of parallel lines or narrow bands which follow the orientation of the grains of metals. They are generally produced by sudden deformation of the metal such as would result from shock, impact or explosion (Sauveur).

Pearlite. — Pearlite is a mechanical mixture (aggregate) of alpha ferrite and cementite which is the principal constituent of slowly cooled annealed steels. It is always associated with an excess of ferrite or cementite except in steels containing between 0.70 and 0.90% carbon (theoretically 0.90% carbon in pure iron-carbon alloy and about 0.85% in commercial steels). It is normal in regions 8A and 8B, Fig. 5. At low magnification it appears as dark irregular grains but at high magnifications it occurs as alternating curved, black and white lamellæ.

Solid Solution (as applied to metals). — A mixture of metals or metalloids in the solid state in which the constituents are completely merged in indefinite proportions.

Sorbite. — Sorbite is a transition stage between troostite and pearlite. It is believed by most authorities to be an uncoagulated conglomerate of irresoluble pearlite with ferrite in hypo-eutectoid and cementite in hyper-eutectoid steels respectively. It is the principal constituent of air-cooled (normalized steels) and of hardened steels reheated to 1,112 to 1,292 degrees Fahr. (600 to 700 degrees Cent.). It has no place in the diagram. It etches more rapidly than pearlite and at low magnifications appears as dark grains (darker than pearlite) surrounded by ferrite boundaries in hypo-eutectoid and by cementite boundaries or globules in hyper-eutectoid steels. In steels containing between 0.70 and 0.90% carbon the structure is practically 100% sorbite after air-cooling. At high magnifications, sorbite appears as a mass of mixed black and white dots. It is harder than pearlite but softer than troostite or martensite.

Steadite. — The binary eutectic of iron and iron phosphide which occurs in gray cast iron.

Troostite. — Troostite is generally believed to be an extremely fine aggregate of the carbide Fe_3C and alpha iron. In the transformation of austenite it is the stage following martensite and preceding sorbite. By some it is considered to be an uncoagulated conglomerate of the transition stages. It is colored decidedly darker than any other constituent by the ordinary etching reagents. It generally occurs as dark-colored irregular areas representing sections through nodules and is generally accompanied by martensite or sorbite or both. It may exist as membranes surrounding martensite grains. Sauveur believes it to exist as the midrib in needles of martensite. Sauveur has suggested

that it may be a solid solution of iron and carbon, probably in the form of the carbide Fe_3C in non-gamma iron.

Twinning. — The grouping of two or more crystals or parts of a crystal in such a way that they are symmetrical to each other with respect to a plane between them (the twinning plane), which plane, however, is not a plane of symmetry (Sauveur).

APPENDIX E (c)

DEFINITIONS

TENTATIVE DEFINITIONS OF TERMS RELATING TO HEAT TREATMENT OPERATIONS*

(Especially as related to Ferrous Alloys)

Foreword. — 1. During recent years certain confusion has arisen in regard to the meaning of commonly used heat treating terms. For instance, in one locality or trade any operation of heating and cooling, resulting in a softening of the material, is being called annealing, whereas in other places to "anneal" means not primarily "to soften" but to heat above the critical temperature and cool very slowly. Similar confusion as to meaning and application exists in regard to other terms and as a result "annealing," "tempering," "normalizing," etc., are being used by different people to mean widely different things.

2. In any attempt to accurately define the terms commonly used in connection with heat treatment, the first question to decide and the most important one is: do the terms relate to the heat treatment operation itself, or to the results obtained by the treatment? In other words, is the term indicative of the structure or the condition obtained, or of the operation performed?

3. After careful consideration, it appears most logical and most in keeping with present day usage to have the terms so defined that they shall mean definite operations and shall not be considered as referring to the resultant structures or general conditions.

4. By "critical temperature range," as used in the definitions, is meant that temperature range illustrated by the diagram given in Fig. 7, taken from Howe.

Definitions

1. **Heat Treatment.** — An operation, or combination of operations, involving the heating and cooling of a metal or an alloy in the solid state.

Note: This is for the purpose of obtaining certain desirable conditions or properties. Heating and cooling for the sole purpose of mechanical working are excluded from the meaning of this definition.

2. **Quenching.** — Immersing to cool.

Note: Immersion may be in liquids, gases or solids.

* These definitions were prepared by a joint committee composed of representatives of the A. S. T. M., S. A. E., and A. S. S. T. Printed from the American Society for Steel Treating handbook, by permission.

3. **Hardening.** — Heating and quenching certain iron base alloys from a temperature either within or above the critical temperature range.

4. **Annealing.** — Annealing is a heating and cooling operation of a material in the solid state.

Note (A): Annealing usually implies a relatively slow cooling.

Note (B): Annealing is a comprehensive term. The purpose of such a heat treatment may be:

(*a*) To remove gases.
(*b*) To remove stresses.
(*c*) To induce softness.
(*d*) To alter ductility, toughness, electrical, magnetic or other physical properties.
(*e*) To refine the crystalline structure.

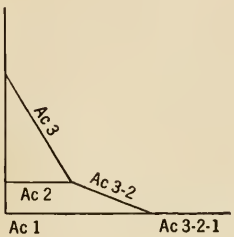

Fig. 7

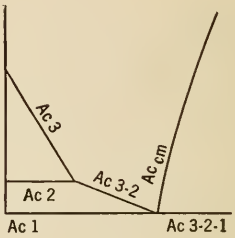

Fig. 8

In annealing, the temperature of the operation and the rate of cooling depend upon the material being heat treated and the PURPOSE of the treatment.

Certain specific heat treatments coming under the comprehensive term "annealing" are:

A. Normalizing. — Heating iron base alloys above the critical temperature range followed by cooling to below that range in still air at ordinary temperature.

Note: In the case of hyper-eutectoid steel, it is often desirable to heat above the Ac_{cm} line, as shown in Fig. 8.

B. Spheroidizing. — Prolonged heating of iron base alloys at a temperature in the neighborhood of, but generally slightly below, the critical temperature range, usually followed by relatively slow cooling.

Note: (*a*) In the case of small objects of high carbon steels, the spheroidizing result is achieved more rapidly by prolonged heating to temperatures alternately within and slightly below the critical temperature range.

(*b*) The object of this heat treatment is to produce a globular condition of the carbide.

C. Tempering (also termed Drawing). — Reheating, after hardening to some temperature below the critical temperature range followed by any rate of cooling.

Note: (*a*) Although the terms "tempering" and "drawing" are practically synonymous as used in commercial practice, the term "tempering" is preferred.

(*b*) Tempering, meaning the operation of hardening followed by reheating, is a usage which is illogical and confusing in the present state of the art of heat treating and should be discouraged.

D. Malleablizing. — Malleablizing is a type of annealing operation with slow cooling whereby combined carbon in white cast iron is transformed to temper carbon and in some cases the carbon is entirely removed from the iron.

Note: Temper carbon is free carbon in the form of rounded nodules made up of an aggregate of minute crystals.

E. Graphitizing. — Graphitizing is a type of annealing of cast iron whereby some or all of the combined carbon is transformed to free or uncombined carbon.

5. **Carburizing (Cementation).** — Adding carbon to iron-base alloys by heating the metal below its melting point in contact with carbonaceous material.

Note: The term "carbonizing" used in this sense is undesirable and its use should be discouraged.

6. **Case-Hardening.** — Carburizing and subsequent hardening by suitable heat treatment, all or part of the surface portions of a piece of iron-base alloy.

Case. — That portion of a carburized iron-base alloy article in which the carbon content has been substantially increased.

Core. — That portion of a carburized iron-base alloy article in which the carbon content has not been substantially increased.

Note: The terms "case" and "core" refer to both case-hardening and carburizing.

7. **Cyaniding.** — Surface hardening of an iron-base alloy article or portion of it by heating at a suitable temperature in contact with a cyanide salt, followed by quenching.

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